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ABSTRACT

This student text presents instructional materials for a unit of science within the Biomedical Interdisciplinary Curriculum Project (BICP), a two-year interdisciplinary precollege curriculum aimed at preparing high school students for entry into college and vocational programs leading to a career in the health field. Lessons concentrate on nutrition in health and medicine and include sections on the digestion of foods, organic chemistry of nutrients, energy and cell respiration, diet, foodborne diseases, food technology, and dental science and nutrition. Reading materials, graphs, illustrations, and problems accompany each of 43 sections. (CS)

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BIOMEDICAL SCIENCE

UNIT II

NUTRITION IN HEALTH AND MEDICINE

DIGESTION OF FOODS; ORGANIC CHEMISTRY OF
NUTRIENTS; ENERGY AND CELL RESPIRATION;
THE OPTIMAL DIET; FOODBORNE DISEASES; FOOD
TECHNOLOGY; DENTAL SCIENCE AND NUTRITION

STUDENT TEXT
REVISED VERSION, 1975

THE BIOMEDICAL INTERDISCIPLINARY CURRICULUM PROJECT

SUPPORTED BY THE NATIONAL SCIENCE FOUNDATION

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SECTION 1: INTRODUCTION TO NUTRITION

1-1 Man and Food

How has man's relation to food changed through the centuries?

From remote villages to sprawling cities food is one of man's chief occupations. We eat not only to stay alive but also to enjoy the pleasure of our friends and family, to satisfy our psychological needs, as well as simply for the sake of taste.

Food is central to life on earth and has concerned man through the ages. Certainly ancient peoples had little knowledge of the chemical nature of food, yet they managed to survive. Through the years, in all parts of the world, cultures evolved different ways of preparing foods and radically different ideas about a proper diet. (Of course, in some regions of the world anything edible was and still is eaten to prevent starvation.) No doubt such diets, which were evolved over thousands of years, were at least adequate. Our ancestors survived long enough to have children, as did their children in turn.

With industrial civilization came dramatic changes in ancient patterns, including what people ate. Population centers grew, fewer people grew their own food and eating in public restaurants became more popular.

As the need for food storage increased, the preservation of food developed into a vast industry. With modern techniques such as freezing, canning, freeze-drying and refrigeration many thousands of different food items have become available to the average person. Simple foods are often passed by for more exotic foods, now available in preserved form.

1-2 Food Patterns and Health

Has modern technology affected our nutrition?

Many people today eat foods which are so new that their nutritional potential remains unproven. Is a diet of hamburgers, French fries and milk shakes able to keep a person as healthy as, let us say, a diet of whole-grain breads, lean meat and noodles, fresh vegetables and fruits? Do various insect- and mold-killing sprays, traces of which remain on our foods, affect our health? While man has made great strides in increasing the food supply, primarily by use of machinery and fertilizer, little is known about the possible long-term effects of newer agricultural chemicals on our health.

Modern methods of food preservation have given us a choice of foods which exceeds that available to many kings who ruled as recently as 200 years ago. Yet we do not fully understand how this great dietary variety affects our health. Is it possible that simpler diets, with more basic foods, are better for our health? We will consider such questions in the Nutrition Unit.

1-3 The Development of Nutritional Science

For untold thousands of years our ancestors roamed the earth hunting and gathering food. Later, farming began and civilizations developed around the most productive lands. Yet, it is only in this century that we have begun to learn about the chemical nature of foods and precisely how specific nutrients contribute to growth and life.

Early in the 20th century the need for high-quality protein for growth was demonstrated by researchers. Later, the needs for vitamins and minerals were discovered. There soon followed studies of amino acids, hormones, enzymes, and various products of digestion and metabolism.

1-4 How the Unit is Organized

Nutritional science is the study of the composition of foods and how man uses the nutrients from food for growth and development. Malnutrition results when we fail to receive or utilize the essential nutrients.

To study "Nutrition in Health and Disease" you will need to know something about what happens to food inside your body. The sections on digestion treat the breakdown of food, the digestive organs and cellular needs. Our health is closely tied to our nutrition. Where appropriate, various illnesses, either related to the digestive organs or influenced by the diet, will be described. A knowledge of nutrition depends, in part, on an understanding of the composition of foods. Here, the chemistry of nutrition will offer us some insights into food and health.

Most of the frontier work in nutrition is being done in cell biology and biochemistry and these areas of study will immediately follow nutritional chemistry. Here, you will see how food is transformed in the cell. Also, you will evaluate your own diet and attempt to devise an "optimal diet" for yourself.

Toward the end of the unit, food processing, the science of microbiology, and food additives will be explored. A description of the effects of parasitic and chemically induced diseases will be given.

A final section has been included which not only treats the anatomy of the teeth and dental disease but also provides an introduction to dental careers.

SECTION 2: HEART DISEASE AND NUTRITION

2-1 The Heart Attack

Was it in the genes?

Peter heard noises coming from his parents' bedroom. It sounded like his father might be in pain or sick. Peter was puzzled. Dad was not the type to complain about his troubles--he had always seemed healthy, never suffered more than an occasional cold, never missed a day of work. Why was he moaning? Peter got out of bed to see what was wrong.

Through the closed door of his parents' bedroom he could hear talking. Dad sounded pretty sure he knew what had happened. He didn't try to pass it off as indigestion or some other minor ailment. Peter heard his father ask his wife to phone the doctor and tell him that he thought he had just had a heart attack.

Peter was overcome with feelings he couldn't contain--shock, fear, confusion. Instead of rushing to his father's side, he ran outside the small frame cottage. The early morning sky was filled with stars. As he watched them, Peter's eyes filled with tears. With his tears came the acceptance that his father had finally had the heart attack he had expected most of his life.

Although only 52 years of age and in apparent "perfect health," Fred Stone had worried about just such an event ever since his own father died of a sudden heart attack at the age of 53. Fred had always felt that a heart attack was "in his genes." He had even completed funeral arrangements when he was a young man.

* * *

Several days later the world seemed different to Peter. He was visiting his father in the hospital. The shock and fear and some of the confusion had disappeared. Dad was out of Intensive Care and he expected to be released in a few days. He seemed to be his old self again. In fact, he had been giving his nurse a hard time about the hospital food. He loved to eat, and he didn't think he was getting enough to live on. Mrs. Schwartz, a clinical dietician, had come to his room to explain his diet. She was in charge of special diets and considered herself an expert on heart cases.

Dad got right to the point with the dietician. "Why can't I have a good meal? I'm starving. Is there a law against desserts in this place?"

Peter sensed that Mrs. Schwartz had anticipated this question. "Mr. Stone," she said with a smile, "you know the old saying about the way to a man's heart being through his stomach? Well, you'd better believe it."

"Look, Mrs. Schwartz. I get enough preaching about diets at home. I'm going to die of a heart attack sooner or later. It's in my genes. So let me go well fed and content. With what I'm paying the hospital, you could toss in three solid meals and some snacks. Right?"

"Wrong, Mr. Stone. There may be something in your genes or there may not be. That's not my specialty, but I've seen your chart and records. They look encouraging. No major damage. Blood pressure normal. You don't have to die of a heart attack if you take care of yourself. Now, your doctor has prescribed that your diet be restricted to 1500 calories a day..."

Fred wasn't about to accept that. "1500 calories! Why..."

The dietician paid no attention to the interuption. She knew who was going to win the argument--at least, while he was still in the hospital. "Mr. Stone. You're not a growing boy. Your heart will be a lot happier if you take off some weight gradually. Your chart says that you are 68 inches and weigh 174 pounds. Considering your age and your build, about 150 pounds would be perfect."

"I've tried diets. They don't work on me."

"Right. Diets don't work on you unless you work on them. It's up to you, and you can do it if you really want to. Later on, the doctor will up your diet, probably to about 2000 calories. But he's also put you on a low-cholesterol, low-fat, low-salt diet, and recommended that you continue with it indefinitely. Watch out for fried foods, syrupy desserts, starchy foods, buttery and creamy things, salty foods. I'll give you a list."

Fred really didn't like the way the conversation was turning out. He lit a cigarette. He didn't know which was worse--the heart attack or the diet. He puffed on the cigarette and tried once again to voice his objections, but the dietician didn't listen. "Mr. Stone," she concluded as she began to leave, "it's your heart. I've got to go. I have a lot of other patients to take care of. And another thing, talk to the doctor about smoking and heart disease. He may want to add a few ideas."

* * *

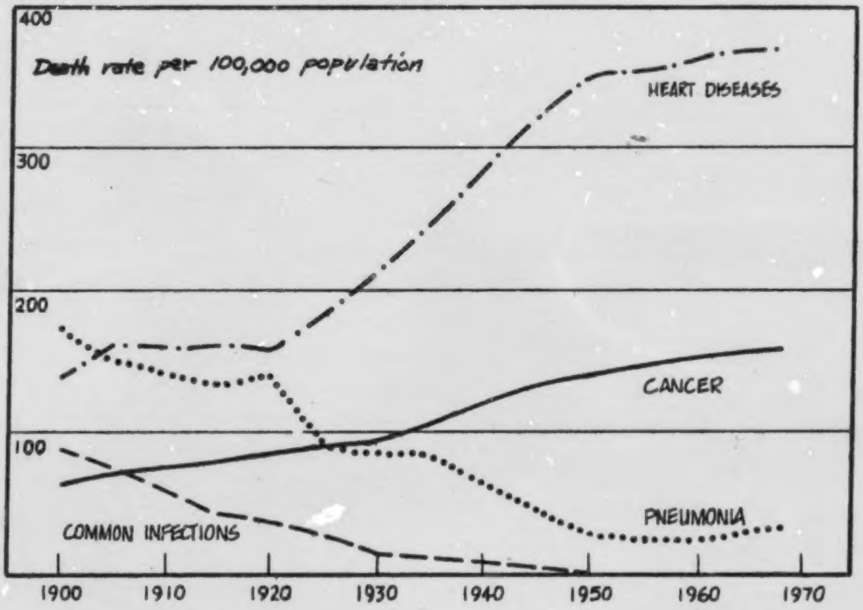
That night Peter was reflective. He pondered the family album and paused at an old picture of his father when he was Peter's age. Dad was sitting very stiffly next to Peter's grandfather. Peter though he had his father's genes for big ears and his grandfather's curly hair.

Still puzzling over genes and heart disease, Peter got up and went out to the kitchen to look for some ice cream or something--a little midnight snack.

2-2 Occurrence of Heart Disease

How has the death rate from heart disease in the United States changed during this century?

In 1900 more people died of pneumonia than of heart disease (see Figure 1). Today a person is about ten times more likely to die of heart disease than of pneumonia. While infectious diseases are generally under control as a result of modern drugs, heart disease and cancer have become the two main causes of death. Peter's father is not alone in his risk of heart attack.



Source: Vital Statistics of the United States.

FIGURE 1: *Several causes of death.*

The death rate for heart diseases increased from less than 150 per 100,000 people in 1900 to over 370 per 100,000 people in 1968. This happened during the same period in which the death rates decreased for pneumonia, tuberculosis and most other diseases caused by infections.

Heart disease is the leading cause of death in the United States, but what does heart disease have to do with nutrition? Was Fred Stone's heart attack related to his diet? Is the increasing death rate from heart disease caused by a change in America's eating habits? In an attempt to answer these questions an important study has been made. Let us examine some of the findings which have resulted from this study.

2-3 The Framingham Study

Is cholesterol associated with coronary heart disease?

A study of approximately 5200 men and women began in 1949 and is still in progress. These people lived in Framingham, Massachusetts, a light industrial and residential town west of Boston. When the study began, the subjects ranged in age from 30 to 62 years. None had a record of heart disease or disease of the blood vessels when the study began. The study involves extensive interviews of the type you discussed in Biomedical Social Science in Unit I.

The purpose of the Framingham Study is to determine what factors are associated with the development of heart diseases and diseases of the blood vessels (called vascular diseases). The subjects have been examined periodically for evidence of the development of these diseases. The Framingham Study is the largest, longest and most careful study of the occurrence of heart disease yet made in the United States. Records have been kept of each person's weight, amount of physical activity, and cigarette smoking habits. The amount of a substance called cholesterol in the blood is determined during the examinations.

In a moment we will examine a graph that presents some of the results of the Framingham Study. But first it is necessary to define a few terms. The coronary arteries are the vessels that supply blood and oxygen to the heart muscle itself. Coronary heart disease is a condition in which the coronary arteries become clogged to one extent or another. As a result, the heart muscle does not receive sufficient blood or oxygen to function properly. You may wish to review the article, "Data on Coronary Heart Disease," assigned in Unit I of Biomedical Social Science.

When the blockage of blood flow to the heart muscle occurs suddenly, we have a "heart attack." That's what happened to Fred Stone in the story. Fred was "lucky." In a substantial number of heart attacks, the heart muscle is damaged so severely that sudden death occurs. Heart attacks often occur during sleep.

Cholesterol is a substance made by the liver as well as obtained from the diet. It is transported to other parts of the body via the bloodstream. Although it has useful functions in the body, excess cholesterol has been suspected for some time to be a contributor to coronary heart disease. For this reason the concentration of cholesterol in the blood has been measured in the Framingham Study. The results are shown in Figure 2 on the following page.

The cholesterol concentration is given in milligrams of cholesterol per 100 milliliters of blood.

Notice that the vertical axis of the graph is labeled "relative incidence." Relative incidence compares the incidence of a disease among a certain group of people to the incidence of the disease among all of the people being studied. It is 100 times the ratio of the risk for some part of a group to the risk for the entire group. Thus a relative incidence of 200 for the group of men with a cholesterol concentration in the range 280-299 means that these men are twice as likely to have coronary heart disease as all of the men in the study combined. On the other hand, the graph shows that those men with a cholesterol concentration below 180 get coronary heart disease only 41 per cent as often as the Framingham men in general.

The graph shows an increase in the incidence of coronary heart disease with increasing cholesterol concentration. Men at the high end of the range are five times as likely to have coronary heart disease as men at the low end. The study therefore supports the idea that high cholesterol levels contribute to heart disease.

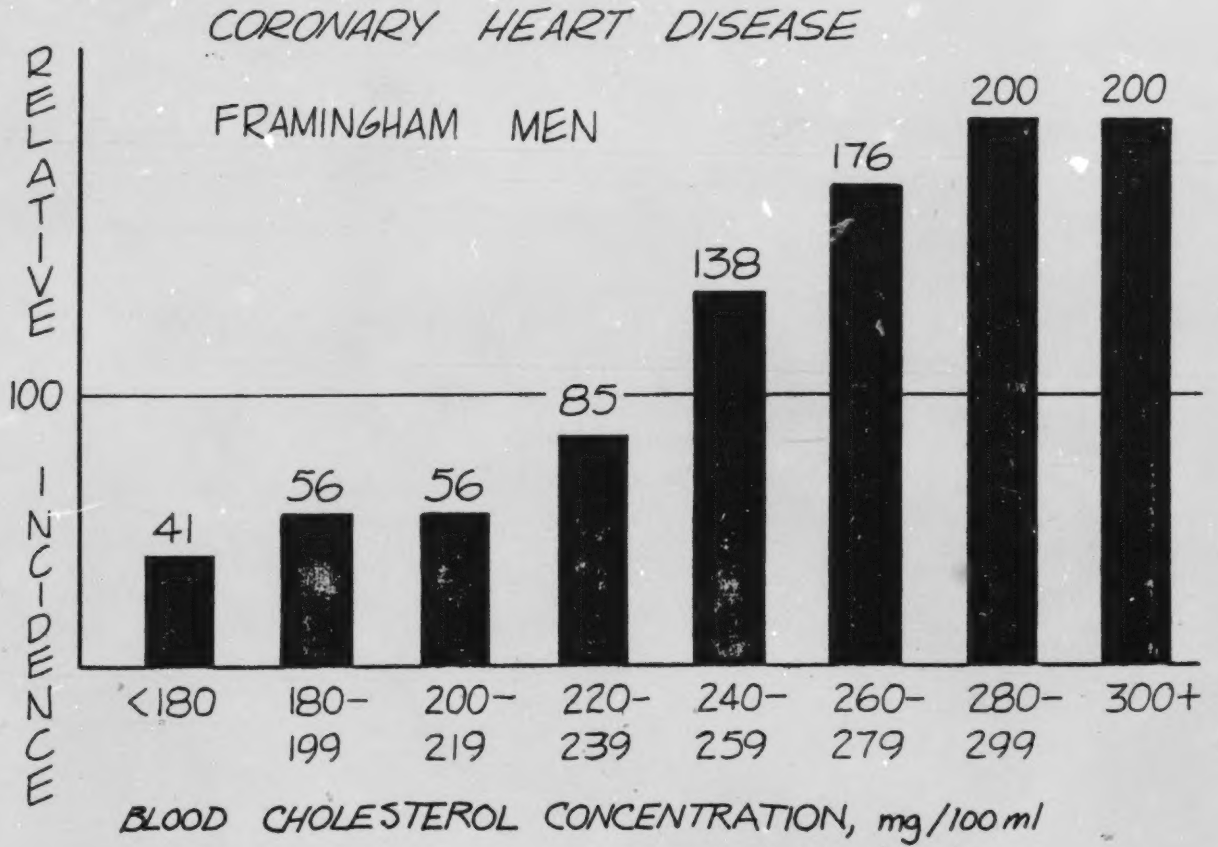


FIGURE 2: *Relation of coronary heart disease and cholesterol.*

This finding suggests that nutrition plays an important role in heart disease. It is the kind of information that made Fred Stone's doctor put him on a cholesterol-lowering diet.

2-4 Fatty Foods and the Heart

Why is North Kyrelia known as "the land of young widows?"

While heart disease is a leading cause of death in the United States, the highest death rate from this disease in the world occurs in a village in Northern Finland. Based on the Framingham Study and on other studies you may have read about, you may associate heart attacks with fat, middle-aged men who have high blood pressure, smoke heavily, and live a highly pressured life. Recall that Fred Stone was a little on the heavy side, middle-aged and smoked. His blood pressure was normal and we really don't know from the story whether he was highly pressured. He had some of the traits indicating that he was a candidate for a heart attack.

In the heart attack capital of the world, the rustic town of North Kyrelia, Finland, most of the victims are lean and muscular. Their occupations are not particularly stressful emotionally or psychologically; they're mainly dairy farmers and lumberjacks. These Finnish people not only have a reputation for being easygoing and friendly, but they live in a natural setting that's relaxing. Yet, 75 per cent of all deaths there come from coronary or related ailments.

Dieticians in Finland think the local diet, which is rich in dairy fats and low in vegetables, is the chief cause of the high incidence of heart attacks. The blood cholesterol level among these people is extremely high.

In Finland, many men drink two quarts of milk a day and also drink fresh cream. The North Kyrelians use butter to bake fish and pastry while the normal lunch for lumberjacks is a fatty sausage or herring and globs of fat wrapped in bread. All of these foods tend to raise the blood cholesterol level.

Most of the men there also smoke and suffer from high blood pressure. So the three factors--diet, smoking and high blood pressure--are the main targets in plans to bring the heart attack rate down. However, the high cholesterol levels are thought to be the leading culprit. The people are being taught how to cook foods with less of the kind of fats that form cholesterol. The three local dairies in North Kyrelia have begun to produce low-fat milk.

2-5 Heart Disease and the Unit on Nutrition

There are a few questions that should be commented on before we proceed. First, why has this section been limited almost entirely to males? Part of the reason is that the relation of diet to heart disease is less clear for females. In addition, up to about age 50, heart attacks are four times as common in males as they are in females After menstruation ceases, however, the female rate rises with time until it finally is about the same as the male rate. The reason for this may have to do with certain hormones that differ in men and women. The nature and functions of hormones will be a subject of later sections.

A second question that we would like to discuss at this point is: Why did Fred Stone have the heart attack--was it his genes or nutrition or what? Unfortunately we can't answer this question. Statistical studies of the kind we have discussed indicate a correlation between many different factors and heart disease. But, as you may recall from Unit I of both Science and Social Science, such studies do not prove a cause-and-effect relationship. What can be stated in a positive way is that several factors increase the risk that a person will have a heart attack. These factors include nutrition (especially cholesterol, fats, salt), excess weight, high blood pressure, smoking, lack of exercise, family history (genes) and personality. We will return to a consideration of the risk factors in heart disease in Unit III when we consider the circulatory system.

One final question to consider is: Why have we spent all this time on heart disease? Our main concern was not the heart and circulation here. It was selected as one example of an important health problem related to nutrition. There are many other diseases affected by our diets and we will consider some of them in the sections to follow.

What were the characteristics of Fred Stone's hospital diet in the story?

What is the leading cause of death in the United States at present?

Was this true in 1900? Explain.

What does the Framingham Study suggest about cholesterol and heart disease? Does the study prove that high cholesterol levels cause heart disease?

List four factors in addition to cholesterol that are associated with coronary heart disease.

What is the diet like in North Kyrelia, the "heart attack capital" of the world? What do dieticians consider to be the major nutritional problem in that community?

SECTION 3: THE DIGESTIVE PROCESS

3-1 The Digestion of Food

What must happen to food before it can enter the body?

As you may know, digestion is the process by which the large, complex molecules of our food are broken down into small, relatively simple molecules. The cells of our bodies must receive nourishment, and the digestion of food is the first step in the process that makes this possible.

The nutrients needed by our cells are carried to them by the bloodstream. For this to happen, the nutrients must be soluble in the blood. In addition, they must be in a form which permits them to be absorbed into the bloodstream through the walls of the intestines.

Digestion accomplishes both of these things. The food molecules are broken down into molecules that are both soluble in blood and small enough to pass into the blood. At the end of their journey, the small molecules pass out of the blood and into the cells where they are needed.

Since you will be dealing with carbohydrates, proteins and fats in the mathematics course, this is a good place to define them. They will be considered in more detail a little later in the unit.

Carbohydrates are sugar molecules or combinations of sugar molecules. Among other functions, they provide energy. Table sugar is made up of two simpler sugar molecules attached together. Other foods rich in sugar are honey, maple syrup, candies and jellies.

Sometimes sugar molecules are combined in long chains as in starch. A few examples of starchy foods are bread, pizza, spaghetti and breakfast cereals. In the sections to follow, we will see that long-chain carbohydrates such as starch are broken down in the digestion process into sugars. These, in turn, are broken down into still smaller molecules within our cells.

Proteins are long chains of amino acid molecules. They vary in molecular weight from several thousand to hundreds of thousands (amu). Some high-protein foods are meat, fish, eggs and soybeans. Proteins, like starch, are broken down in the digestion process. The products of protein digestion are amino acids. These substances can enter cells where they may be restructured into proteins needed by the body. Proteins are an important part of our body structure (hair, bones, skin and so on).

Fat molecules are large in comparison to such molecules as NaCl, acetic acid and amino acids. However, they are much smaller than protein and starch molecules. A few examples of fatty foods are salad dressings, butter, walnuts and sausage. Fats are similar to proteins and starch in that they are broken down in the digestive process into smaller molecules. Gram for gram, fats provide the most calories of any class of nutrients.

Calories are not nutrients, but they are important in any consideration of the diet. They are a measure of the energy content of food. It is important that the caloric value of the food we eat be neither too high nor too low. In this country, too many calories in the diet is often a concern. Such diets can result in obesity.

Examples of high-calorie foods include fatty and starchy foods. By contrast, green leafy vegetables and many fresh fruits are low in calories.

3-2 Anatomy of the Digestive System

What are the organs that compose the digestive system?

In Unit I, it was necessary to examine the structure and parts of the respiratory system in order to understand the process of respiration. It is equally necessary to examine the digestive system in order to understand digestion and nutrition.

The simplest way to picture the digestive system is as a tube of varying size running through the body. Food enters one end of the tube, the mouth. As the food travels along, part of it is digested and absorbed through the walls of the tube. What is left over passes out through the other end, the anus.

As can be seen from the figure on the next page, the digestive tract is folded back on itself many times and would be about eight meters long if stretched out. It consists of several distinct parts, each having a different function.

The entrance to the digestive system is the mouth, which includes the teeth, tongue and salivary glands. Digestion begins in the mouth. Food passes from the mouth down a tube called the esophagus to the stomach. Food is temporarily stored in the stomach, and further digestion takes place there.

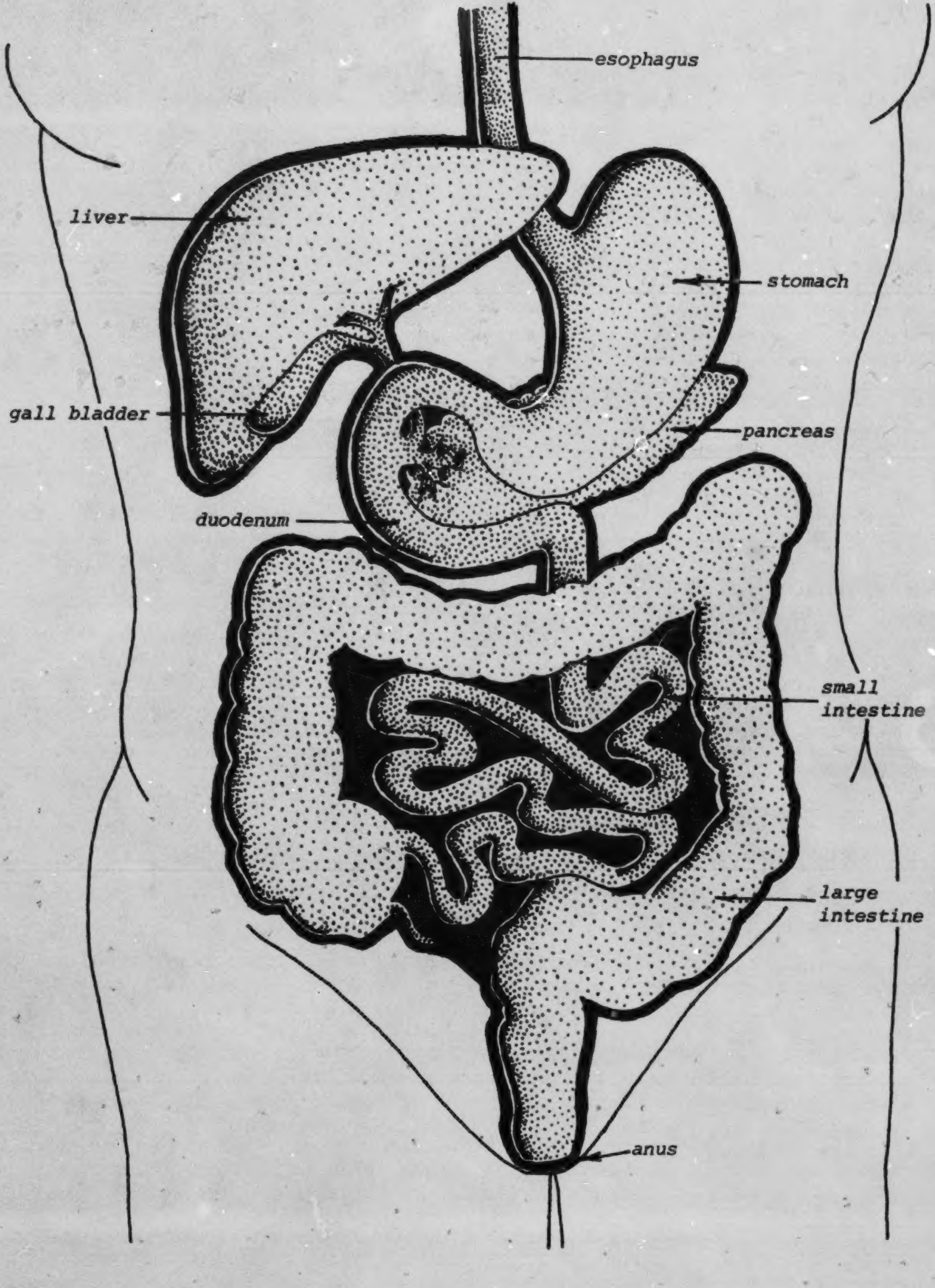
From the stomach, partially digested food enters the small intestine. The first 25 to 30 cm of the small intestine are called the duodenum. Three glands, the pancreas, the liver and the gall bladder, release materials into the duodenum to aid digestion. Digested food is absorbed through the surface of the small intestine into the body. What has not been absorbed in the small intestine passes into the large intestine, where further absorption takes place. The undigested residue leaves the body at the opening of the large intestine, called the anus.

In this section, we have barely touched on the organs of digestion and their functions. Our purpose was simply to provide an overall picture of what happens to the food we eat. In the sections to follow, we will return to each of the organs of digestion and examine the processes that occur within them in more depth.

3-3 Anatomy and Adaptation

How is the gastrointestinal tract adapted to its function?

The folding of the digestive tract permits a great length of tubing to be housed in a relatively small volume. If it were limited to a straight tube from the mouth to the anus, the length would be less than a meter instead of eight meters. This increase in length has a real advantage. It increases the surface area available for absorption of food. As you read the text, you will find countless examples of anatomical structures (organs, cells, even molecules) that have an "architecture" beautifully suited to their functions. We speak of these structures as being adapted. Most biologists believe that adaptation (the process of becoming adapted) is the result of millions of years of evolution. The theory of evolution will be considered in a later unit. In the meantime, it will be very helpful to raise questions about the relation of anatomical structure to function. In most cases, you will find that our structure is consistent with function. For example, you might consider how the lungs are adapted to providing the body with oxygen.


esophagus
liver
stomach
gall bladder
pancreas
duodenum
small intestine
large intestine
anus

What is the function of the digestive process?

What are three major classes of nutrients in our diet?

What happens to these nutrients during digestion?

What are calories a measure of?

In Section 2-1, Fred Stone was placed on a low-fat, low-calorie diet. What are some foods he should watch out for?

Cover up the labels on p. 12 and see how many of the organs of digestion you can identify.

List all the structures a hot dog or its remnants will pass through en route from one end of the digestive tract to the other.

What is meant by "adapted?" In what way is the digestive system adapted?

What are some other examples of human adaptation?

Vocabulary:

adaptation--process of becoming adapted.

adapted--well suited for a particular function.

calorie--a measure of the energy content of food.

carbohydrate--a nutrient composed of sugar molecules or chains of sugar molecules.

digestion--the splitting of food substances into smaller molecules which can be absorbed into the body.

fat--a class of energy-rich nutrients.

nutrient (NEW-tree-unt)--a substance in foods necessary to maintenance of health.

protein--a nutrient composed of a long chain of amino acids.

tract--a succession of organs serving a particular function.

SECTION 4: ENZYMES

4-1 The Chemistry of Digestion

Why are enzymes needed in digestion?

We have seen the path taken by food as it passes through the digestive tract and how the food is broken down. The breakdown process is both mechanical and chemical. In the mouth, food is mechanically broken into small pieces by the teeth. Yet these small pieces are far too large to be absorbed into the body. It is the chemical changes that convert the food into molecules small enough to be absorbed. This chemical process is of fundamental importance because a continuous supply of molecules is needed for our cells to sustain life. Yet the chemical reactions by themselves would be too slow to prevent starvation if there were not more to the story. The missing links are molecules known as enzymes, substances that serve to speed up the chemical reactions of digestion. Enzymes are essential to our survival.

4-2 The Discovery of Enzymes

What was in the yeast?

Eduard and Hans Buechner were concerned neither with food nor with human digestion. The brothers were Swiss pharmacists. At the turn of the century, they were trying to isolate and study new drugs. They were working on an extract from yeast. The procedure was to take live yeast (one-celled fungus organisms), add sand and chemicals, and grind the mixture with a pestle. Then they would extract liquids and test them for drug action. But they were afraid that bacteria and molds in the air would get into their preparations and spoil them.

How could they preserve their extract? They did not want to add chemical preservatives, because those available in the early 1900's were poisonous. This was undesirable because they wanted to use the drugs produced on people. The brothers decided that they would try an old device that was used for preserving foods--they would add excess sugar to provide a mixture in which bacteria cannot grow. (This technique is still used by home canners.)

One day one of the brothers happened to look at the "yeast preserve." He noticed tiny bubbles being released. On closer inspection, he detected a smell of ethyl alcohol. Wine was being produced! He was stunned. Fermentation was occurring in a mixture containing dead yeast. Something in the yeast was doing what he and other scientists of his time believed could only be done by living organisms. That "something in the yeast" was changing sugar into wine. Hans and Eduard had no idea what the mysterious factor was, so they called it "enzyme" from the Greek words meaning "in yeast."

In time, it was shown that many of the enzymes in yeast are similar to those in humans. The unexpected discovery of enzymes in yeast excited the scientific community and caused a whole new field of science to emerge--biochemistry.

4-3 Catalysts

How does a catalyst affect a chemical reaction?

Enzymes belong to a class of chemical substances called catalysts. Such substances change the rate of chemical reactions without themselves being permanently changed.

You may recall from Unit I generating oxygen gas by heating potassium chlorate with a small amount of manganese dioxide. Oxygen gas may also be obtained from potassium chlorate alone. In that case, however, the temperature must be considerably higher and the oxygen is produced at a much slower rate. The MnO_2 still remains in the test tube.

As another example, let's consider the breakdown of hydrogen peroxide, H_2O_2. You may have used this substance as an antiseptic and noticed tiny bubbles released. This happens because hydrogen peroxide very slowly decomposes to water and oxygen.

$$2\ H_2O_2 \rightarrow 2\ H_2O + O_2$$

The reaction is sufficiently slow that we may leave hydrogen peroxide on the shelf of a medicine cabinet for several months.

But if even a small quantity of manganese dioxide is added to hydrogen peroxide, the peroxide decomposes rapidly to water and oxygen. The manganese dioxide is unchanged in the reaction; the same quantity remains that was added.

The presence of a catalyst in a reaction is indicated in the equation by writing its formula above the arrow.

$$2\ H_2O_2 \xrightarrow{MnO_2} 2\ H_2O + O_2$$

Instead of adding manganese dioxide to the hydrogen peroxide, you could do the following: take a small piece of raw beef, grind it up just as the Buechner brothers did, and add an extract of the beef to the hydrogen peroxide. If you did this, you would find that the beef extract would also speed up the decomposition of the hydrogen peroxide, because the extract contains an enzyme. Both the enzyme and manganese dioxide are catalysts, yet they are very different in their chemical nature and in their properties.

4-4 Properties of Enzymes

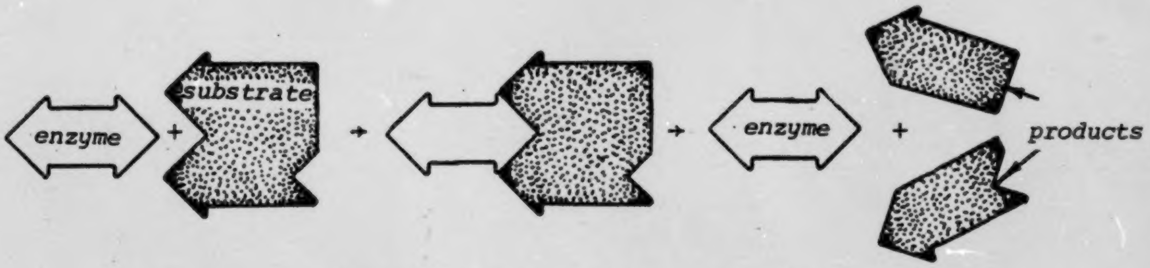
What are some of the differences between a catalyst like manganese dioxide and an enzyme?

Enzymes are proteins. As such, they are very large molecules compared to MnO_2 and other non-biological catalysts. Each enzyme has a unique arrangement of amino acids. Recall that proteins are one of the major classes of nutrients (Section 3). In fact, one of the reasons why proteins are such an important component of food is that some of the amino acids that the cells obtain as a result of digestion of proteins are rearranged to form enzymes.

Enzymes differ from MnO_2 not only in their size, but also in their greater sensitivity to their environment. For example, many enzymes are most effective as catalysts at body temperature (37 °C). A few degrees increase in temperature often inactivates an enzyme, thus essentially stopping a reaction, while the same temperature change would actually increase the rate of a reaction catalyzed by MnO_2. Each enzyme has a particular pH at which it functions best. Some are most effective at a neutral pH, others at an acidic pH. MnO_2, and many other non-enzyme catalysts, are less affected by pH.

MnO_2 functions by itself as a catalyst. Although some enzymes are self-sufficient, others require additional factors to operate, such as vitamins and minerals. This is one of the reasons why these vitamins and minerals are such important nutrients.

Enzymes are highly discriminating catalysts. They can detect very slight chemical differences between substances. It is remarkable that an enzyme acts so specifically on one compound. It might be easier to understand this highly discriminating process by using a model to describe it. Though an enzyme is actually a molecule of high molecular weight, in our model we will picture an enzyme as a puzzle piece that must fit the molecule on which it acts. We call this molecule the substrate. Thus we can represent an enzymatic reaction as in the following figure.



Model of an enzyme-catalyzed reaction.

Note that the enzyme is not changed in the reaction and that it may go on to catalyze the breakdown of other molecules.

Enzymes are usually named according to the substrate on which they act. This makes learning the names of enzymes easier. The first part of the name derives from the compound on which it acts. To this is generally added the suffix "-ase." The enzymes that catalyze the breakdown of carbohydrates are called carbohydrases. Proteinases act on proteins.

What two different processes work to break down our food into smaller pieces?

Could digestion occur in the absence of enzymes?

What is a catalyst? What is a biological catalyst?

What is the chemical nature of enzymes?

What are some ways in which enzymes differ from non-biological catalysts?

How is an enzyme named? What are enzymes called that break down proteins?

Explain the model of a reaction shown in the figure on p. 16.

Vocabulary:

catalyst (KAT-uh-list)--a chemical substance that speeds up a reaction without being altered in the process.

enzyme (EN-zime)--a biological catalyst.

substrate--a substance on which an enzyme can act.

SECTION 5: DIGESTION IN THE MOUTH AND STOMACH

5-1 Digestion in the Mouth

How is food altered in the mouth?

In Section 3 we outlined the process of digestion. Over the next several sections, we will consider each stage of the process in more detail. You may find it helpful to review the figure on p. 12 periodically to visualize each stage of digestion in relation to the complete system.

The mouth is where digestion begins. Three features of the mouth are significant in starting the process of digestion. Two of these, the teeth and tongue, play a mechanical role--they work together to break the food into smaller pieces. The third feature, saliva, begins the chemical breakdown of starch.

Saliva is secreted by the salivary glands. Since we will encounter several glands and secretions associated with the digestive system, these terms are worth defining at this point. A gland is an organ that produces a substance that is needed elsewhere in the body. A secretion is any substance released by a gland.

As shown in Figure 1, there are three salivary glands on each side of the face. Each gland has an outlet from which saliva is secreted into the mouth. If you've ever had the mumps, you may recall a pain and swelling in the face just below the ear. These symptoms are caused by inflammation of one of the salivary glands.

Although saliva is sometimes thought of in an unpleasant way as just "spit," the

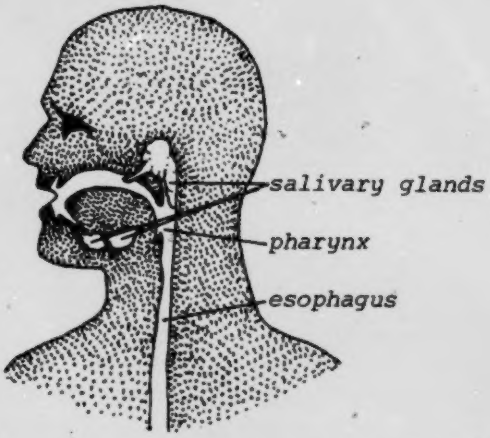


FIGURE 1: *Location of the salivary glands.*

functions of saliva are many and important. Saliva washes the teeth. It keeps the mouth moist and makes speech easier. It helps neutralize acids. It dissolves some food making it possible for us to taste food. And it lubricates food and thus makes swallowing easier.

When food enters the mouth and chewing begins, nerve signals are sent from the mouth to the brain. These signals contain information about the taste and texture of the food. The brain, in turn, stimulates the salivary glands, and saliva is secreted. Even contemplating appetizing food can set off impulses that stimulate the salivary glands and "make the mouth water."

Saliva contains the enzyme, amylase. In Section 4 we discussed how limited enzymes are in the reactions they can catalyze. Amylase acts on starch but on no other type of nutrient.*

Since food remains in the mouth for only a limited time, starch is only partially digested in the mouth. So the food passing to the stomach contains some undigested starch, some starch molecules that have been broken into shorter chains and some sugar molecules, which are the final breakdown product of starch digestion. The food also contains undigested protein and fat which amylase does not affect.

This mixture is swallowed and enters the esophagus. Swallowing begins as a voluntary action, an action we can consciously control. Food is maneuvered to the back of the tongue as we chew. The tongue is then jerked downward, allowing the food to pass through the pharynx and enter the esophagus (see Figure 1). You may recall the pharynx from Unit I, since it also serves as a passageway for air.

5-2 From Mouth to Stomach

How does swallowed food get to the stomach?

Once food enters the esophagus, we have no further voluntary control over it. Layers of muscles are located in the walls of the esophagus. These muscles can tighten like a belt and form a constriction as indicated in Figure 2, opposite. The constriction forces particles of partly digested food slightly forward. These muscles then relax while muscles slightly below constrict, thus moving the food a bit farther. This results in a wave of contraction which travels downward, pushing food ahead of it. The overall process is a little bit like taking an open tube of toothpaste and squeezing it from the bottom to the top. The toothpaste will be forced toward (and out of) the open end. The muscular process is called peristalsis. The wave that results is a peristaltic wave (Figure 2).

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* You might expect an enzyme that breaks down starch to be called "starchase." Actually starch is a mixture of two long-chain carbohydrates, one of which is called "amylose." Amylase is also a carbohydrase, but this latter term is less specific since it does not indicate what type of carbohydrate is broken down by the enzyme.

It is peristalsis that causes food to pass from the mouth to the stomach, not gravity. If gravity caused food to pass along the digestive tract, would astronauts in orbit be able to digest their food? Can you think of a way to prove that gravity is not the cause of the movement of food along the esophagus?

5-3 Digestion in the Stomach

What types of digestion occur in the stomach?

The stomach is located on the left side of the body, the lowermost part of the organ being approximately level with the bottom of the ribs. Food entering the stomach contains undigested protein, fat and starch, as well as sugars.

The presence of food in the stomach stimulates the secretion of several types of glands embedded in the lining of the stomach. The word "gastric" comes from the Greek word for stomach, so this mixture of secretions is called gastric juice. The three main components of gastric juice are a dilute hydrochloric acid solution, mucus and a chemical called pepsinogen.

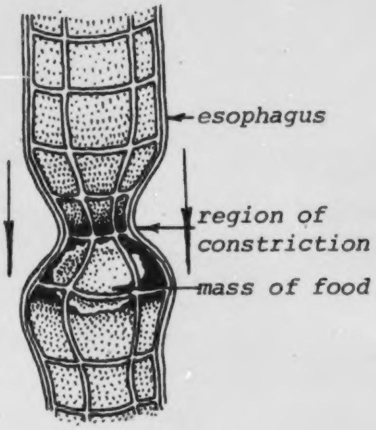


FIGURE 2: *A peristaltic wave.*

The HCl secreted in the stomach has a number of important functions. It continues the process begun with chewing by breaking up large particles of food into smaller particles and single molecules. It also dissolves some minerals and kills most (but not all) of the bacteria that enter the stomach with food. In addition, HCl is responsible for the conversion of pepsinogen into an enzyme called pepsin. ("Pepsin" comes from the Greek word for digestion.) Pepsin is a proteinase; it catalyzes the breakdown of proteins into short chains of amino acids.

While pepsin begins the digestion of proteins, this process is only about ten per cent completed when food leaves the stomach. Likewise, little digestion of fats takes place in the stomach; most occurs after the fats reach the duodenum. The amylase, from saliva, continues the digestion of starch to some extent. However, amylase is not active in an acidic environment. (Recall that an enzyme is most effective at a particular pH.) When amylase comes into contact with H^+ ions in the stomach, it is inactivated.

Thus digestion is far from complete in the stomach. The stomach's main function is to serve as a temporary storage place for large bulks of food while mixing it with gastric juice. The stomach churns the food, and passes it on at intervals in regulated amounts to the intestine, the main digestive organ.

The stomach functions in a way that allows us to eat at irregular intervals. We need not always have food in our mouth to provide a steady flow of needed chemicals to our cells. For example, we may complete a meal in 15 minutes, but the food is slowly passed into the intestine over three to five hours. This provides a constant supply of nutrients into our bloodstream and into our cells. This is a fortunate adaptation. If this were not the case, perhaps we could only function a small part of the day.

Food is prevented from going back up into the esophagus or from passing on too quickly into the intestine by means of sphincters. They are valve-like structures located at both ends of the stomach. A sphincter is a ring of muscles going around the tube. The sphincter between the esophagus and stomach opens when we swallow, vomit or burp. The other sphincter, known as the pyloric valve, regulates the amount of food that is emptied into the intestine.

Vomiting is a reverse peristalsis. Stomach and even upper intestinal tract contents are forced back through the esophagus in waves that go in the wrong direction. These waves force partly digested food to exit through the mouth. This process is coordinated by the brain. (Vomiting can serve a very useful purpose if we swallow spoiled food.)

What three features of the mouth are important in starting digestion?

What are the functions of saliva in digestion?

What causes the "mouth to water?"

What do amylase and pepsin do? Where do they operate?

What is peristalsis? How does a peristaltic wave move?

What do the glands in the lining of the stomach produce?

How much digestion occurs in the stomach? (much, little)

What is the main function of the stomach?

What prevents food from going back up into the esophagus?

What useful purpose can vomiting serve?

Why doesn't the food we eat enter the trachea? (Hint: To answer this, you may want to review Unit I, Section 10.)

Vocabulary:

amylase (AM-ih-lace)--a digestive enzyme that catalyzes the breakdown of starch; a carbohydrase.

esophagus (eh-SAHF-uh-gus)--the part of the digestive tract between the mouth and the stomach.

gastric juice--fluid secreted by glands lining the stomach; it contains HCl, pepsinogen and mucus.

gland--an organ that produces a substance needed elsewhere in the body.

pepsin (PEP-sin)--an enzyme that catalyzes the breakdown of proteins in the stomach; a proteinase.

peristalsis (PAIR-ih-STAHL-sis)--a wavelike progression of alternating constriction and relaxation of muscles.

saliva (suh-LY-vuh)--fluid secreted by the salivary glands.

salivary gland (SAL-uh-VAIR-ee)--one of the six glands that secrete saliva into the mouth.

secretion (sih-KREE-shun)--a substance released by a gland.

sphincter (SFINK-tur)--a ring of muscle capable of contracting to close off a passageway.

SECTION 6: CASE HISTORY: PEPTIC ULCER

6-1 Case History: Female, Age 29

Maria slammed down the telephone and reached into her desk drawer for a bottle of little white pills. As she popped a couple of them, the TV commercial ran through her mind. "Acid-Gone not only relieves the acid in your stomach, it also has a gentle calming agent that soothes irritated nerves."

She dropped the bottle back into the drawer and sat back to wait for the pain in her stomach to stop.

She'd always had a "sensitive stomach," but until recently she could settle it with a little bicarb of soda. During the last couple of months her stomach had become a real problem. She was learning the ropes in a new job, and it was twice as hard because there were a couple of men in the office who didn't like having a woman tell them what to do. She intended to stick it out, but her stomach seemed to be staging a rebellion.

It was a curious kind of pain. It usually started about an hour before mealtime, and ten minutes after she ate, it would be gone. Around bedtime it would start up again, but a glass of milk would make it go away. However, the milk seemed to have an undesirable side effect. In the last two months she'd put on ten pounds.

Today, though, it seemed different. When the pain came on around eleven o'clock it wasn't any worse than usual, but she felt a little nauseated--didn't feel like eating. She was a little sweaty, and when her secretary came in with a pile of papers to be signed she said that Maria looked pale. She felt anxious and fatigued at the same time.

* * *

By the time she got home from work she was all in. She flopped on the sofa and tried to get some rest.

When her husband got home half an hour later, he was surprised to find Maria flat on her back.

"Things getting worse at the office?" he asked.

"Things are getting worse in my stomach," she said. "I'm glad you're home." She started to sit up, but she felt like she was about to faint and fell back again.

"Hey, you're really sick. What's the matter?"

"I don't know," she said. She was surprised by the weakness of her voice. "Call the doctor."

"Okay." He went into the kitchen to make the call, and in a couple of minutes he was back.

"What did he say?"

"Well, I told him about your stomach pains, and about the way you look now, and he just said he'd meet us at Center Hospital Emergency."

* * *

Dr. Miller quickly examined Maria. He noted that she was sweaty, her hands and feet cold and pale, her blood pressure low--80/60--and her pulse about 120. He very gently examined her abdomen and noted that it was soft, which was normal, and not especially tender. He admitted Maria to the hospital's intensive care unit.

After examining Maria, Dr. Miller was almost certain that she had a bleeding peptic ulcer. Her history of taking antacids like bicarbonate of soda, and the fact that she had previously been able to relieve the abdominal pain by eating, were typical of ulcer. And the appearance of mild shock--low blood pressure, high pulse and sweatiness--without any increase in pain almost always meant bleeding. That the bleeding originated in her digestive tract was confirmed several hours later when Maria's bowel movement was noted to be very dark--almost black--and a chemical analysis of her feces revealed the presence of blood.

* * *

After two blood transfusions, diet therapy and some drugs, Maria's condition quickly stabilized. Five days after her entry, an X-ray confirmed the presence of an ulcer.

6-2 Peptic Ulcer

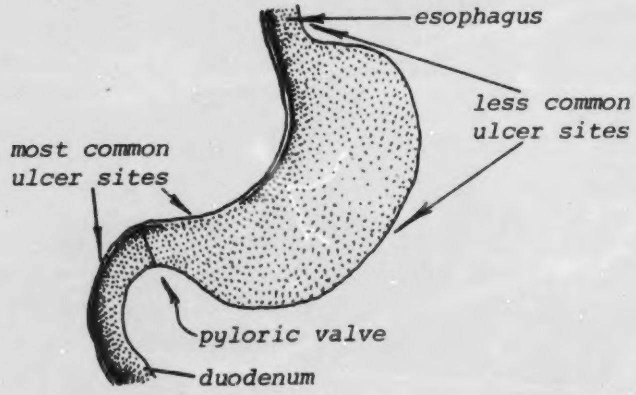
What is a peptic ulcer and how is it treated?

As you may recall from your laboratory experience, HCl is a potent acid. Fortunately, the stomach wall is equipped with a series of defenses to protect it from the action of hydrochloric acid. These include the secretion of a protective mucus that we discussed in Section 5, the capability of the stomach lining to repair itself at a rapid rate, and the fact that normally acid is secreted in quantity only when food is in the stomach.

A balance exists between secretion of hydrochloric acid to digest food and the defenses designed to protect the stomach lining. A shift in this balance may create a situation which permits the acid to digest the lining of the stomach. The causes of such a shift are not completely understood. The secretion of mucus may be inadequate to protect the stomach. In some patients excesses of pepsinogen and acid are secreted. In others, gastric secretion may continue at a high level when food is not present in the stomach. There is also evidence that in some cases psychological or emotional stress may lead to such an imbalance, although the mechanism by which this happens is unclear. When a condition is caused by psychological factors, it is said to be psychosomatic (psycho = mind, soma = body).

Whatever the cause of the imbalance between secretion and the protective mechanisms in the stomach, the result is often a lesion or sore in the lining of the digestive tract. This lesion is what we call a peptic ulcer. The pain and burning associated with an ulcer may be partly due to the hydrochloric acid acting on nerves exposed by the lesion.

A peptic ulcer may occur in the stomach, in which case it is called a gastric ulcer, or in the duodenum, in which case it is a duodenal ulcer. About 90 per cent of all ulcers occur in the upper section of the duodenum. Gastric ulcers occur most frequently in the inner curve of the stomach and in the area of the pyloric valve. Their occurrence in the outer curve of the stomach and in the lower esophagus is less common.



Sites of peptic ulcers.

Television commercials which show a stomach bubbling with too much acid can be misleading. Such commercials are about acid indigestion, not ulcers. Stomach acid, in normal amounts, is essential to the well-being of the stomach. Recall that acid is required for the formation of pepsin from pepsinogen and also that pepsin is effective only at an acidic pH.

How did Dr. Miller determine that Maria was suffering from a peptic ulcer? He found two initial clues in the history that she gave him. The first of these was the fact that she obtained temporary relief from pain by eating. This pain-food-relief sequence is much more common in duodenal ulcer than in gastric ulcer. This is understandable because, not only does food decrease the effect of the acid on the stomach lining, but its presence in the lower end of the stomach and the duodenum also stimulates the release of fluids which neutralize the acid passing into the duodenum from the stomach. Because patients who have a duodenal ulcer obtain relief by eating, they may eat more frequently than normal. A consequence of this is that patients with duodenal ulcer commonly gain weight.

In contrast to the duodenal ulcer, pain from a gastric ulcer may be aggravated by eating. This is thought to be due to mechanical irritation, i.e., rough food rubbing up against the ulcer. In such cases the patient may lose weight because eating makes him uncomfortable.

Another difference between the symptoms presented by duodenal and gastric ulcers has to do with the amount of acid and pepsinogen that the patient secretes. In most of the cases of duodenal ulcer the patient produces excessive amounts of acid and pepsinogen when secretion is stimulated. However, patients with gastric ulcer usually secrete normal amounts when tested. These findings reinforce the idea that the cause of ulcer is not as simple as "increased gastric secretion," but is more complex and varies from person to person.

The second clue in Maria's history that indicated an ulcer was her report that she obtained temporary relief of pain by taking antacids. This finding is common to both duodenal and gastric ulcers.

An antacid tends to neutralize the acid of the stomach. Antacids that can be obtained without a prescription commonly contain sodium bicarbonate ($NaHCO_3$). Bicarbonate ions convert hydrochloric acid to carbonic acid by the following reaction.

$$HCO_3^- + HCl \rightarrow H_2CO_3 + Cl^-$$

Part of the carbonic acid formed dissociates to carbon dioxide and water, and the overall effect is to reduce the acidity. Although such antacids do relieve symptoms, their prolonged use is not recommended. Bicarbonates are absorbed into the blood, and here they may neutralize hydrogen ions by the reaction

$$H^+ + HCO_3^- \rightarrow H_2CO_3$$

You may remember the importance of the hydrogen ion concentration (pH) of the blood in controlling breathing. Excess bicarbonate in the blood lowers the hydrogen ion concentration and raises the pH. The condition of high blood pH is alkalosis. (Respiratory alkalosis was caused by Tom's hyperventilation.) Because constant use of bicarbonate antacids can lead to alkalosis, doctors usually prescribe an antacid that remains in the digestive tract and is not absorbed into the blood.

The other symptoms exhibited by Maria when she was admitted to the hospital, low blood pressure, sweatiness and cold hands and feet, indicate mild shock, a condition often caused by loss of blood. The doctor already suspected an ulcer from the temporary relief provided by eating and antacids. The symptoms of shock suggested to him that blood was being lost. That the loss originated in the digestive tract was confirmed by the analysis of Maria's feces, which were darker than normal because of the presence of digested blood. Maria not only had an ulcer, she had a bleeding ulcer. Bleeding occurs when the ulcer damages the lining of a blood vessel.

The presence of a peptic ulcer was confirmed by an X-ray. Because the digestive tract itself does not normally show up on an X-ray the patient is given a drink of barium sulfate, which coats the digestive tract. Since barium sulfate appears opaque in the X-ray, it is possible to visualize the digestive tract by using this method. Defects in the stomach wall or duodenum can sometimes be demonstrated by this process.

Once an ulcer has been diagnosed, treatment is begun. The object of this treatment is to relieve pain and to heal the ulcer. Antacids are usually the primary medication used. Antacids relieve pain quickly and neutralize the excess acid that sometimes causes ulcers. As mentioned before, antacids that do not rely on bicarbonate ions are preferable. Also because the stomach is constantly emptying its contents into the duodenum, antacids must be given at short intervals (about one hour) to insure their continued effectiveness. In the case of an ulcer in which hypersecretion is present, a drug may also be given to suppress gastric secretion. If emotional factors are thought to be significantly involved, tranquilizers may also be prescribed.

Caffeine and alcohol are generally prohibited for ulcer patients, because both of these drugs are known to increase gastric secretion. In addition, cigarette smoking is banned. For some unknown reason, smoking retards the healing of ulcers.

The effectiveness of special diets in the treatment of ulcers is questionable. However, when employed, dietary treatment is intended to neutralize excess acid and to encourage healing by avoiding foods that irritate the ulcerated area. Several small meals are preferable to a few large meals. Large meals stretch the stomach and cause greater secretion of gastric juices. Many small meals, however, result in food being in the stomach a greater percentage of the time. This is particularly helpful in the case of duodenal ulcer for reasons stated previously. Smaller meals also reduce the irritating effect that food may have on gastric ulcers.

Peptic ulcer was traditionally treated with a diet that emphasized drinking milk and cream many times a day. These foods are rich in fat, and the presence of fat in the stomach causes food to be retained longer before it is released to the duodenum.

Despite the possible benefits of a diet including the frequent consumption of milk and cream, this practice is no longer recommended for ulcers. Excessive milk and cream result in a diet that is too high in calcium and fats. Such diets may lead to other medical problems.

It was assumed for many years that a diet of mild foods (a bland diet) was preferable to a more normal diet. However, recent investigations discount this theory. It has been shown that the rate of recovery of peptic ulcer patients with normal diets is not significantly different from the recovery rate of patients with bland diets.

The current attitude toward dietary treatment of peptic ulcer is to suit the diet to the individual patient. Specific foods that irritate a patient's digestive tract are excluded.

Surgery is required in only a small fraction of peptic ulcer cases. It is used only if the patient has suffered frequent recurrences or complications. The preferred surgical treatment is removal of part of the stomach. This not only rids the patient of the ulcer but decreases the number of gland cells secreting acid and pepsinogen which may decrease the chance of a recurrence. If the doctor feels that emotional factors are the predominant cause, he may recommend that the vagus nerve be cut. The reason for this is that emotions such as anxiety, etc., can cause secretion of gastric juice. The vagus nerve is the pathway by which the nerve signals are transmitted to the stomach.

Peptic ulcer is one of the more common disorders of modern America. Between 10 and 15 per cent of our population at one time or another suffer from ulcers. Duodenal ulcer is most common between the ages of 20 and 50, while gastric ulcer may occur at any age. Peptic ulcer is the fourteenth most frequent cause of death in the United States, being responsible for 0.5 per cent of all fatalities. If an ulcer remains untreated, it may eventually penetrate through the stomach wall. This is called a perforation (opening). It is an extremely serious complication and can result in death if not treated promptly.

How is the stomach lining protected from the action of HCl?

What is a psychosomatic illness?

What is a peptic ulcer? In which two organs does it occur?

How do antacids relieve the pain of a peptic ulcer? Why is it a bad idea to use antacids frequently without consulting a physician?

What kinds of treatment may be used with ulcers?

Why was Maria a good candidate for an ulcer?

Since caffeine should be avoided in cases of peptic ulcer, what beverages should be eliminated?

Vocabulary:

duodenal (DEW-o-DEE-nul or dew-OD-en-ul)--pertaining to the duodenum.

duodenum (DEW-o-DEE-num)--the first part of the small intestine, beginning at the pyloric valve.

lesion (LEE-zhun)--a sore or wound.

peptic ulcer (PEP-tik)--a lesion in the lining of the stomach or duodenum.

psychosomatic (SY-ko-so-MAT-ik)--caused by psychological factors.

SECTION 7: DIGESTION IN THE DUODENUM

7-1 From the Stomach to the Duodenum

What controls the rate at which the stomach empties itself?

We have traced the digestion process from the mouth to the stomach. Yet food is far from digested when it exits the stomach. After leaving the stomach, partially digested food enters the first 25 cm of the small intestine, known as the duodenum. The process of digestion does not gain "full steam" until the food reaches this region. In this and the next section, we will examine what happens to food in the intestines.

You may recall that food enters the duodenum through a sphincter called the pyloric valve (Section 5-3). The partially digested food in the stomach, called chyme, is mixed and moved along by a series of peristaltic waves, similar to those of the esophagus. When a wave of contraction reaches the pyloric valve, it too contracts and squeezes a small amount of the chyme into the duodenum. The rate at which food moves out of the stomach is determined by the strength of these contractions. When the contractions are strong, the food enters the duodenum more rapidly.

But what controls the strength of the contractions? One factor is the amount of chyme in the stomach. But the most important factor is the chemical composition and the amount of chyme in the duodenum.

Protein, fat, acid and even the pressure exerted by the chyme stimulate glands located in the walls of the duodenum to secrete hormones.

Hormones are a special class of secretions that are released into the bloodstream and are carried by the blood to other organs where they have an effect on the functions of those organs. (The secretions of the salivary glands, for example, are not hormones; because they are released directly into the mouth, rather than the bloodstream.)

Thus the duodenal hormones are released not into the duodenum, but into the blood. Some of them are carried to the stomach, where they act on the nerves that control the contractions of the stomach, causing the contractions to become weaker. We will see shortly that these hormones have other effects, as well.

Fats in the duodenum are especially effective in slowing down the emptying of the stomach. For example, a high-fat meal, such as eggs and milk, may take more than six hours to pass out of the stomach, while a meal of protein and carbohydrate may take less than four hours. This is a useful adaptation, since fats are digested and absorbed more slowly than most other components of food.

7-2 How is pH Regulated in the Duodenum?

One of the enzymes active in the duodenum is amylase, which you may recall breaks down starch into sugar. Amylase is active in the mouth, but becomes inactive in the stomach because it functions only at pH values near neutral. The chyme entering the duodenum from the stomach is acidic. How then can starch digestion occur in the duodenum?

The answer, once again, lies with the duodenal hormones. They are carried in the blood not only to the stomach, but also to the pancreas. The pancreas is an extremely active gland. In response to the duodenal hormones, it secretes up to about 2.5 liters of pancreatic juice each day into the duodenum. One of the functions of this juice is to regulate the pH of the duodenum.

The pancreatic juice contains a high concentration of bicarbonate ions (HCO_3^-). These ions react with the HCl in chyme to form carbonic acid (H_2CO_3) and chloride ions. Since carbonic acid is a much weaker acid than HCl, the bicarbonate helps to neutralize the acid originating in the stomach. This is similar to the action of antacids used to treat peptic ulcers.

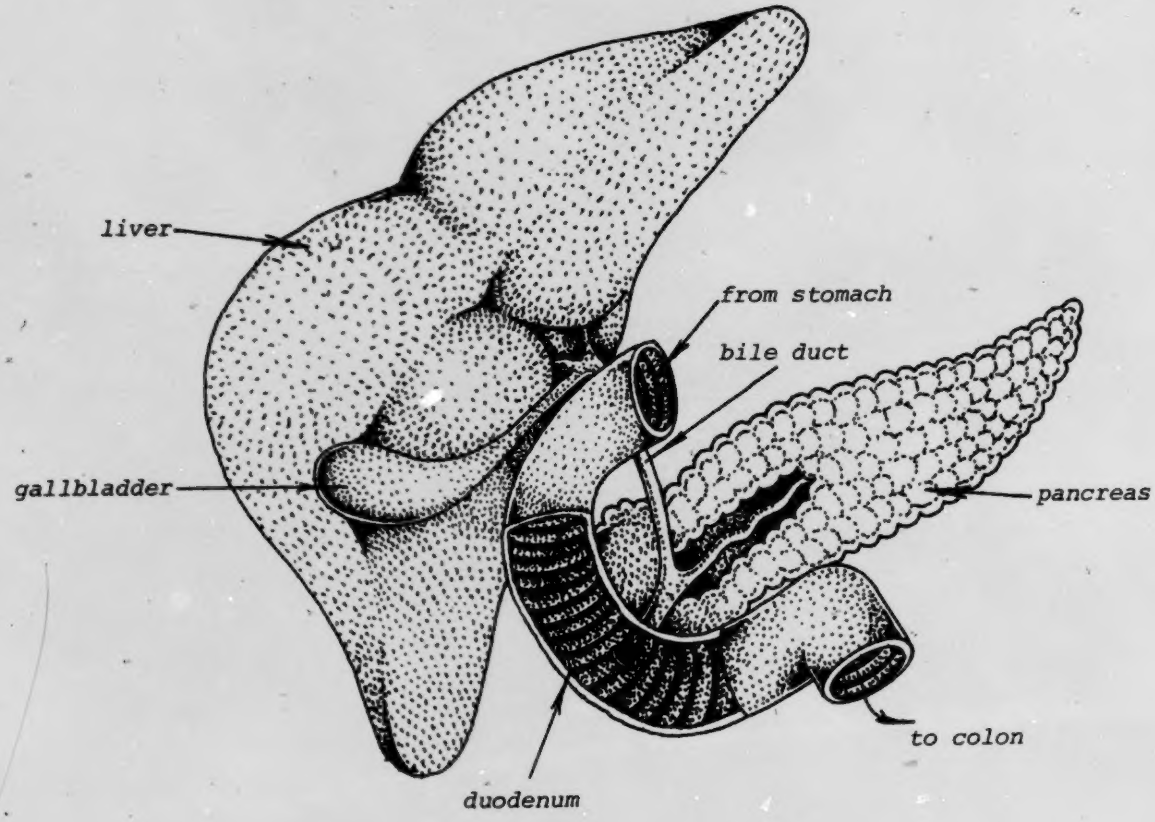
$$HCO_3^- + HCl \rightarrow H_2CO_3 + Cl^-$$

7-3 The Liver

What is the role of the liver in the digestive process?

The liver is an extremely large organ. Weighing about 1500 g, it represents about two per cent of the total body weight in adults.

The liver lies beneath the diaphragm and is mainly on the right side. It is divided into four lobes, the right-most lobe accounting for two-thirds of its weight, and the smaller lobes the rest. The liver is surrounded and protected by the ribs.



Several Digestive Organs

The liver is one of our most important organs and serves us in a variety of ways. The liver may be viewed as a factory that produces many chemicals essential for life. For example, this organ is the major site of cholesterol synthesis. In Section 2, we considered evidence linking cholesterol to heart disease. Yet, modest amounts of cholesterol are necessary for us to function. Cholesterol is a component of the membrane that surrounds each of our cells. Moreover, cholesterol is converted in the body to many other needed compounds.

Another important function of the liver is to convert some poisons in food into less harmful compounds that are easy to excrete. This is called detoxication.

One of the most significant contributions of the liver to the digestion process is the production of a substance called bile. Bile is needed for the breakdown of fat in the duodenum.

7-4 Bile and the Solubility of Fats

How does bile help to digest fats?

Once the pH in the duodenum has been adjusted, a whole series of digestive enzymes released in the pancreatic juice can begin to catalyze the breakdown of proteins, carbohydrates and fats.

The enzyme that breaks down fat is called a lipase because chemists classify fats with a group of substances called lipids. Lipids are not grouped together because of chemical similarity, but rather because of similar solubility properties--they are insoluble in water and soluble in many organic solvents. This solubility property of fats creates a problem in digestion.

Since fats are insoluble in water, they separate from water as oil separates from vinegar. On the other hand, lipase is soluble in water but not in fats. The problem confronting the body is to make a large area of contact between lipase and fat; if they are not in contact, lipase cannot catalyze the breakdown of fat.

Oil and vinegar can be mixed by shaking; however, the movement of food in the duodenum is not vigorous enough to mix the water layer and the fat layer.

Two insoluble liquids can be caused to mix by forming an emulsion. An emulsion is a system in which one liquid is suspended in another. A substance that cuases one liquid to form an emulsion in another is called an emulsifying agent. An emulsifying agent prevents two liquids from forming separate layers by keeping one dispersed in small droplets in the other. Water and grease form separate layers, but soap causes grease to form an emulsion; this is why soap is used to wash greasy dishes.

An emulsifying agent in the duodenum causes fat to form small droplets. The emulsifying agent is bile, the substance we discussed in the section on the liver. Bile is produced by the liver and then stored in a pear-shaped organ known as the gallbladder. (You may recognize this organ as the place where gallstones are formed.) The gallbladder lies close to the right lobe of the liver and holds up to about 45 ml of bile.

When food, especially fat, enters the duodenum, one of the hormones secreted by the duodenum travels through the blood to the gallbladder. The hormone causes the gallbladder to contract and empty its stored bile into the bile duct (see figure, p. 29). Bile passes from the gallbladder to the duodenum. There the bile causes large fat drops to separate into small droplets. As you may recall from the discussion of alveoli in the Respiration Unit, many small objects have a greater total surface area than an equal volume of large objects. This is also true of fat droplets. The large number of small droplets in the emulsion have a greater area of contact with lipase than a smaller number of large droplets would. The result is that fats are almost completely broken down by lipase in the duodenum.

Why are the secretions of the salivary glands not classed as hormones?

What characteristics of the chyme in the duodenum work to slow the emptying of the stomach? Which component of chyme is most effective in retarding stomach emptying?

What are some of the important substances produced by the liver? What are the functions of these substances?

Where is bile produced? Where is it stored? How does bile contribute to fat digestion?

What is the function of the pancreas in digestion?

What causes the pH to drop in the stomach? What causes it to rise in the duodenum?

What role is played by the duodenal hormones in the digestive process?

Vocabulary:

bile--a fluid produced by the liver and stored in the gallbladder; it is secreted into the duodenum, where it aids in the digestion of fat.

bile duct--a tube through which bile passes from the liver and gallbladder to the duodenum.

chyme (KYME)--partially digested food.

detoxication (dee-TOK-sih-KAY-shun)--the process of converting a harmful compound into one that is less poisonous and more easily excreted.

emulsion (ee-MUL-shun)--a mixture of two liquids in which one liquid is dispersed in small droplets thoughout the other.

emulsifying agent--a substance that causes two liquids that do not mix well to form an emulsion.

gallbladder--a hollow organ located just beneath the liver; stores bile.

hormone--a substance produced by a gland and transported in the bloodstream to other parts of the body, where it causes an effect.

lipid (LIP-id)--a group of compounds, including fats, that are insoluble in water but soluble in many organic solvents.

liver--a large organ located beneath the diaphragm and surrounded by the ribs.

pancreas (PAN-kree-us)--a gland that secretes digestive enzymes and bicarbonate ions into the duodenum.

SECTION 8: DIGESTION AND ABSORPTION IN THE INTESTINES

8-1 Digestion in the Small Intestine

What must happen in the small intestine before absorption can occur?

In the previous sections, we have followed the breakdown of food as it progressed down the digestive tract. We have almost completed the discussion of digestion.

The chyme, as it passes from the duodenum through the small intestine, contains a mixture of digestion products. The fats are completely digested and are ready to "enter" the body. (In a sense, all of the digestive tract may be considered to be outside the body. It is only when the nutrients pass through the lining of the digestive tract and enter the bloodstream that they are truly part of the body.) While the digestion of fats is complete, proteins and carbohydrates are not completely broken down. What we have in the small intestines is a mixture of different-sized fragments as indicated schematically in the table.

Components of Chyme in the Small Intestine	Symbols
X	X = fat breakdown products
$S + \underbrace{S\text{-}S + S\text{-}S\text{-}S + \ldots}_{\text{complex carbohydrates}}$	S = sugar
$A + \underbrace{A\text{-}A + A\text{-}A\text{-}A + \ldots}_{\text{fragments of proteins}}$	A = amino acid

When food enters the lower section of the small intestine, an intestinal juice is secreted by glands in the lining of the intestine. This juice contains enzymes which digest the complex carbohydrates that are not fully broken down. In addition, enzymes are secreted to complete digestion of proteins. Peristaltic waves slowly move chyme through the small intestine just as similar waves carried food down the esophagus. Moreover, contractions regularly occur along the intestine. These contractions, in the form of rings, separate the intestine into small segments (see Figure 1). The segmentation helps to bring the digested food into close contact with the lining of the intestine. This is important because absorption of digested food into the body begins in the small intestine. Absorption is the transfer of nutrients across the intestinal wall.

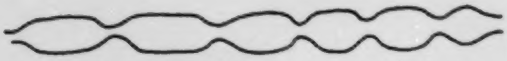


FIGURE 1: *Segmentation in the small intestine.*

8-2 Absorption of Nutrients into the Body

How is the body adapted for absorption?

Figure 2 shows a cross-section of the small intestine and an expanded view of a small section of the intestinal wall. The walls of the small intestine are lined with millions of tiny hair-like projections called villi from the Latin word for "shaggy hair." (The singular is "villus.") These villi are about a millimeter long. They are in constant motion. This motion or agitation may be viewed as an adaptation; it helps to keep the chyme and enzymes mixed and to bring digested nutrients into contact with the lining. The villi have another key function, for they are the site of absorption. Note the irregular shape of the intestinal wall in Figure 2A. How is this irregular surface adapted to absorption?

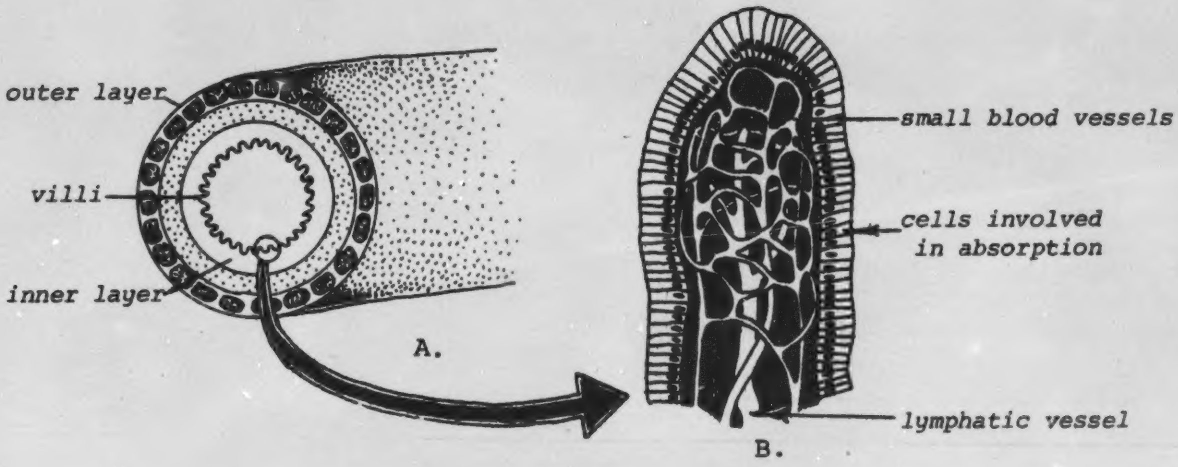


FIGURE 2: A. *Cross-section of small intestine.*
B. *Interior structure of a villus.*

A nutrient molecule passes through cells lining a villus (Figure 2B). Amino acids and sugars enter the blood system via small blood vessels (capillaries). These capillaries lead to larger vessels. Eventually, these vessels carry amino acids throughout the body.

The digestion products of fats, however, follow a different route. Once inside the cells of the villus, the breakdown products recombine into fats. The fats, which are not soluble in water,* collect into tiny droplets and enter the small vessels of the lymphatic system. The lymphatic system gets its name from the clear fluid it carries, "lymph." The path taken by the digested fat after it enters the lymphatic system will be treated in a later unit when we discuss the lymphatic system in some depth.

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*Fats are an exception to the rule that digestion makes molecules water soluble.

Those vitamins that are water soluble are absorbed into the blood system, while the others (the fat-soluble vitamins) are absorbed into the lymphatic system. The fat-soluble vitamins are not absorbed efficiently unless bile is present to emulsify them. For this reason, a lack of bile can lead to a vitamin deficiency even in a diet rich in vitamins.

By the time chyme reaches the end of the small intestine, most nutrients have been absorbed into the body, but the digestive process has not quite been completed. The chyme is soaked with water that has come to it from the blood supply. This water must be reabsorbed by the body. This is accomplished in the next part of the system, the large intestine.

8-3 The Large Intestine

How is water reabsorbed? What happens to food that cannot be digested?

The large intestine is only about 1.2 m in length (Figure 3). It is much wider (about 6 cm in diameter) than the small intestine, thus its descriptive name. Little actual digestion takes place in it. The walls of the large intestine do not have villi and the large intestine secretes no digestive enzymes. Yet it plays a significant role in the digestive process. Its main function is to re-absorb water from chyme. It also stores and releases feces.

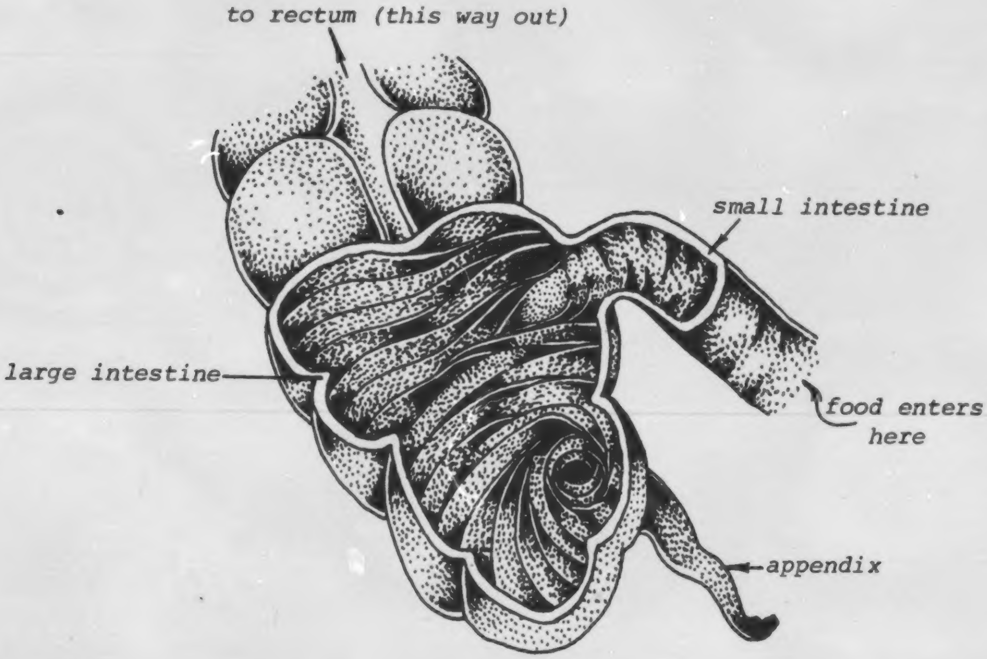


FIGURE 3: *Junction between the large and small intestines.*

Chyme passes from the small intestine into the large intestine only at intervals. This is regulated by a sphincter at the junction of the two intestinal structures, which opens when the stomach receives a meal. The appendix is below this point (Figure 3). Appendicitis is an inflammation of the appendix. It may result from blockage or from an infection. When an appendix is surgically removed before the appendix breaks, recovery is almost certain. Removal of an appendix (appendectomy) is a routine operation. If, however, the appendix breaks, feces are released into the body cavity. Such waste material can cause an inflammation of the membrane that covers the digestive organs and lines the wall of the abdomen (peritonitis). Thus, an early removal of the inflamed appendix is important. While surgery always entails a risk, it is safer to operate than to risk peritonitis.

Chyme remains in the large intestine for a long time. Peristalsis there is very slow, allowing time for water absorption. The substances that remain constitute the feces.

Feces contain undigested materials, and discarded cells from the digestive tract. Although the body jealously absorbs water from chyme in the large intestine, fortunately the feces are still about 70 per cent water. (If our wastes were too dry it would be painful and difficult to defecate.)

Feces are passed to the last portion of the large intestine known as the rectum. This structure is about 12 cm long and ends with a sphincter called the anus.

Digestion is a complex process that takes place in a number of stages and at different sites along the length of the digestive tract. The table on the next page provides an overview of the complete process.

What is "absorption?" At what point in the digestive process is food ready for absorption?

Describe the chemical nature of the nutrients when they arrive in the small intestine.

What is secreted in the intestinal tract? Compare this fluid with other fluids secreted elsewhere in the digestive tract.

What propels the chyme forward in the intestines? Where else does this kind of motion occur?

What role do villi play in digestion? How are they adapted for their function?

Which nutrients enter the capillaries in the bloodstream and which go into the vessels of the lymphatic system?

How do the small and large intestines differ in structure and function?

SUMMARY OF DIGESTION

Digestive Structure	Mechanical Action	Fluid(s) Secreted	Enzymes Present	Digestion of		
				Proteins	Fats	Carbohydrates
Mouth	chewing swallowing	saliva	salivary amylase (SA)			starch digestion begins
Esophagus	peristalsis		SA			continues
Stomach	churning peristalsis	gastric juice	SA pepsin	begins	very slightly	continues
Duodenum and Small Intestine	absorption peristalsis	bile pancreatic juice intestinal juice	lipase amylase proteases carbohydrases	completed (amino acids)	completed	starch and other carbohydrates completed (glucose)
Large Intestine	reabsorption of water, very slow peristalsis					

Where is water reabsorbed from the chyme?

What is appendicitis? How might a ruptured appendix lead to peritonitis?

Vocabulary:

absorption (ab-SORP-shun)--the passage of substances from the digestive tract into the bloodstream or lymphatic system.

anus (AY-nus)--the sphincter which serves to close off the rectum.

appendix--a structure near the junction of the small and large intestines.

feces (FEE-seez)--excretions from the intestine containing undigested food.

lymphatic system (lim-FAT-ik)--the system for transport of fats and fat-soluble vitamins.

rectum--the last portion of the large intestine.

villi (VIL-eye)--minute projections of the wall of the small intestine; site of most absorption of nutrients.

SECTION 9: DISORDERS OF THE DIGESTIVE SYSTEM

9-1 Hepatitis

What are the two forms of viral hepatitis?

There are many important medical problems related to the digestive system. We have already referred to heart disease and peptic ulcers. In this section, three major illnesses related to the digestive organs will be discussed, along with a number of minor complaints.

Hepatitis is becoming increasingly common in the United States and is considered first. "Hepatic" means "related to the liver." The suffix "-itis" means "inflammation" so hepatitis is an inflammation of the liver. Incidentally, many seemingly difficult medical terms become easy to define if you take the words apart. For example, what is "laryngitis?"

Hepatitis may be caused by certain chemicals, drugs, bacteria or viruses. We will direct our attention to inflammations caused by viruses, or viral hepatitis. There are actually two different kinds of viral hepatitis. One is called "infectious hepatitis" and the other is "serum hepatitis." Both types are increasingly important health problems in this country.

In a sense, the term "infectious" may be a little misleading. Both are infectious--they can be passed from one individual to another. But they are caused by different viruses and the virus that causes infectious hepatitis spreads more easily, explaining its name. On the other hand, serum hepatitis can be spread only via *serum*, explaining its name. (Serum is the clear fluid that can be extracted from clotted blood.)

Infectious hepatitis is transmitted when the food or water consumed by a person has been contaminated by even tiny amounts of the virus from a previous victim. This virus is found in feces, urine and blood. It is most likely to spread as a result of unsanitary food handling. Infectious hepatitis may also be transmitted through contact with contaminated blood. For example, you could get infectious hepatitis from a blood transfusion. Because of its transmission through food and water, infectious hepatitis may occur as an epidemic.

Infectious hepatitis is probably more common than thought because most cases are mild and usually go unrecognized. However, a mildly ill person can give someone else a severe case of hepatitis.

In contrast with the infectious hepatitis virus, the serum hepatitis virus can be transmitted from one person to another only through blood. For this reason, epidemics of serum hepatitis are unlikely to occur. Cases can often be traced to a transfusion from an infected person via a blood bank. One outbreak was caused by a doctor who did not sterilize a syringe and infected 40 patients, but this sort of occurrence is very rare. More often, serum hepatitis is passed to only one person at a time. For example, a drug user who shares a needle with a friend may also share hepatitis. At one time, tattoo parlors were a frequent source of serum hepatitis. However, with better sterilizing techniques and with laws regulating these parlors, tattooing has become much safer.

People infected with infectious hepatitis develop symptoms two to six weeks after the virus enters their body. Serum hepatitis takes longer to be noticed--from six weeks to six months. However, the symptoms of the two types of viral hepatitis are almost identical. In 80 per cent of infectious hepatitis cases and 20 per cent of serum hepatitis cases the first signs are symptoms such as fever, fatigue and loss of appetite that cannot be attributed to a specific disease. Headaches and disorders of the *gastrointestinal tract*, such as diarrhea and vomiting, may also occur. It is also of interest that many smokers develop a distaste for cigarettes at this stage.

The symptoms could indicate many disorders. However, as the disease progresses, symptoms develop which are more specific for hepatitis. The first of these is that the person's urine turns dark yellow. The second symptom is the condition known as *jaundice*. Jaundice is characterized by a yellow color in the skin and the whites of the eyes.

Jaundice and dark yellow urine are both caused by an excess in the blood of a pigment called bilirubin. Red blood cells are continually breaking down and being replaced. When they break down, hemoglobin molecules within the cells also break down. One product of the breakdown is the yellow-colored substance bilirubin.

Bilirubin is carried by the blood to the liver. One of the many functions of a healthy liver is to filter bilirubin from the blood system. Bilirubin is released by the liver to the gallbladder along with bile, and subsequently secreted into the duodenum. Bile, you may recall, is needed to emulsify fats, but bilirubin has no function in the process of digestion. It is secreted into the digestive tract to remove it from the body. It is bilirubin that explains the normal dark color of feces.

When a person is suffering from hepatitis, his liver cells are under attack by the virus. A large number of cells are inflamed and many of them die. Because the liver is damaged, it may be unable to remove bilirubin. As a result, excess bilirubin accumulates in the blood and eventually ends up in the tissues, where its presence produces the yellow color known as jaundice. Excess bilirubin may also be excreted in the urine, giving it a dark yellow color.

When making a diagnosis of hepatitis, a doctor will inquire whether the patient has been exposed to hepatitis. He will conduct a physical examination, noting whether the liver is enlarged and tender, and whether the patient is jaundiced. Then a number of laboratory tests will be performed. The patient's blood and urine will be examined for the presence of bilirubin. Tests may also be done for certain enzymes in the blood that stem from the breakdown of liver tissue.

Unfortunately, no drug is known to destroy the virus that causes either type of hepatitis. No treatment is effective in curing hepatitis. The liver must recover on its own. In order to make it easier for the liver to recover, certain substances that irritate the liver are avoided. Among these substances are alcohol and most drugs. It is important that the hepatitis victim be provided with a good diet during recovery. Sufficient protein is of particular importance to provide adequate supplies of this nutrient for the repair of damaged liver tissue. Of course, any food that causes gastrointestinal distress should be avoided.

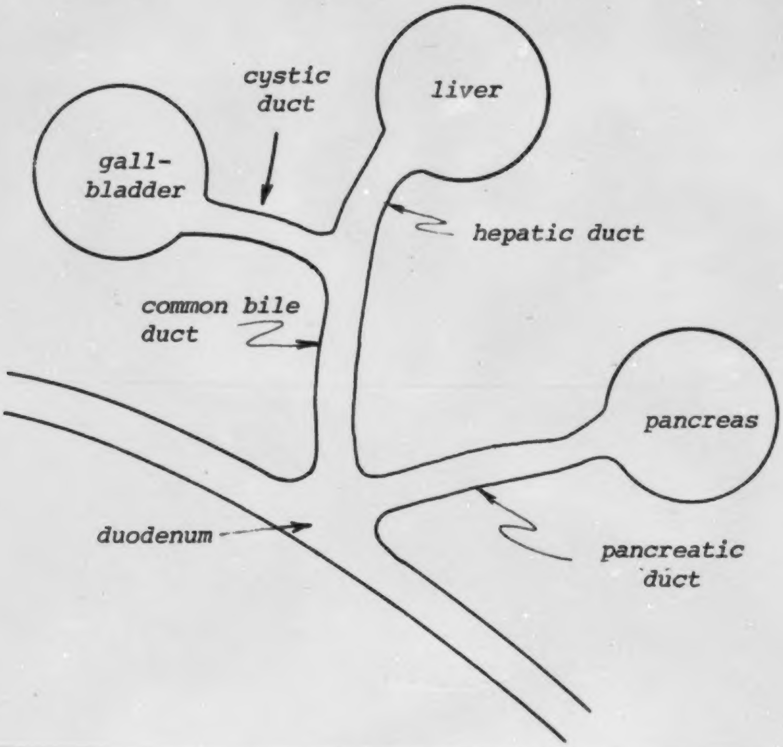
A person who has had infectious or serum hepatitis becomes immune to a second attack of this disease for a few years. Immunity results from manufacturing blood proteins known as antibodies. Antibodies are very specific for a given disease. Thus, a victim of infectious hepatitis is not immune to serum hepatitis, nor is a person who has had serum hepatitis immune to infectious hepatitis.

A person suspected of having recently been exposed to a hepatitis virus can sometimes be protected by receiving an injection of a mixture of blood proteins from a large number of different donors. Such mixtures of "pooled" blood are maintained at blood banks. Pooled blood may include samples of blood proteins from 10,000 or more donors. The assumption is that some of the donors will have recuperated from infectious hepatitis and will have antibodies in their blood. In actual experience, this treatment does not prevent hepatitis, but lessens the chance of serious liver damage.

9-2 Gallstones

How are gallstones detected?

In order to understand the problem of gallstones, it is necessary to review the anatomy of the digestive tract in the area of the duodenum. The parts of the anatomy that are relevant are the duodenum, liver, gallbladder, pancreas, and particularly the ducts connecting them. The are illustrated in the following diagram. (This is a schematic diagram; the organ sizes are not realistic.)



Organs Related to Gallstones

Gallstones are masses of solid matter that form in the gallbladder. As you may recall from the laboratory, they are most commonly composed of cholesterol, bilirubin, bile salts and calcium salts. It is not known why gallstones form, but it is known that women have a greater tendency than men to develop gallstones, and that they develop more frequently in individuals over 40 and in individuals with diets high in fats and calories. A person may have one large stone or as many as 200 small stones.

Half of the individuals with gallstones show no symptoms. The others may have mild symptoms, such as belching or a feeling of being bloated, or they may experience extreme pain. Pain is caused by the passage of a stone through the cystic and common bile ducts or by a stone becoming lodged in one of these ducts. Pain is most likely to occur after a meal, because it is then that the gallbladder is stimulated to release bile to the duodenum.

Obstruction of the common bile duct also prevents bilirubin from being excreted. As indicated in the discussion of hepatitis, when bilirubin is not excreted, it accumulates in the blood. The accumulation of bilirubin in the blood causes jaundice. A positive diagnosis of gallstones can sometimes be made with X-rays using special dyes.

Gallstones may present a number of complications. For example, if one of the ducts is obstructed by gallstones so that bile is not released to the duodenum, the digestion and absorption of fats is impaired. The most serious complication that can occur is the development of cancer of the gallbladder. Seventy-five per cent of people with this type of cancer also have gallstones.

There is no drug that one can take for gallstones. If the condition becomes sufficiently serious, the stones or even the entire gallbladder must be removed surgically. Fortunately, a person can function satisfactorily after removal of the gallbladder. The liver will release the bile directly into the duodenum.

9-3 Pancreatitis

What is pancreatitis? How is it caused?

In a small number of cases, gallstones may cause inflammation of the pancreas, or pancreatitis. As discussed in Section 7, the function of the pancreas is to secrete digestive juices into the duodenum. These juices contain proteinases, the enzymes that break down proteins, but in an inactive form so that they do not attack the pancreas itself.

A gallstone can block the pancreatic duct or any of the smaller ducts branching from the pancreatic duct. If this happens, pancreatic juice is trapped in the pancreas. Proteinases may become activated in the pancreas and inflame the lining.

Gallstones can also block the common bile duct in such a way that bile enters the pancreas. It is not certain whether bile irritates the pancreas directly or activates enzymes which then attack the pancreas. Whichever is the case, bile is associated with pancreatitis.

Treatment for pancreatitis often involves a modified diet. The foods are generally bland and the use of alcohol is discouraged. In addition, drugs to ease the pain may be prescribed.

9-4 Other Digestive Tract Problems

What is the usual cause of heartburn and indigestion?

The gastrointestinal (GI) tract has been called "the sounding board of the emotions." Why is that? Recall some common emotional situations--"a lump in the throat," "mouth as dry as cotton," "the sight of it made me vomit." You can probably think of many others. The fact is that much happens in the GI tract that is not due to disease, but still represents a change in normal body function. These changes are usually due to some type of alteration in the nervous system as a result of emotional and psychological factors. Recall our earlier reference to psychosomatic illness.

Consider common magazine, radio and TV advertising regarding the digestive tract. We hear a great deal about "stomach acid," "stomach gas," "heartburn," "indigestion" and all the wonderful things that occur when we take the right drugs. What is really wrong? In most cases not very much. "Stomach gas" is probably the simplest. Where does the gas come from? Is the gas a product of faulty digestion? In most cases, no. It is often the result of swallowing air, usually from eating too fast and/or swallowing too often. Nervous tension and anxiety are almost always involved to some degree. The treatment should be to recognize the cause and eliminate it; a pill is usually not the answer.

Indigestion involving "stomach acid" may be a little harder to correct. Medication seems to work well, but does not solve the problem. The discomfort due to acidity often returns again and again because the drugs are treating the "effect" without removing the "cause." The cause of excessive secretion of gastric juice is often related to deep-seated psychological and emotional factors. Anger has definitely been shown to affect the stomach. Whatever can be done to channel one's energies into constructive activities usually helps to improve GI tract function (this includes "heartburn," "indigestion" and lower tract problems).

Another GI tract area that is sometimes exploited by the medicine makers is constipation. The idea that is too often suggested is that we must be "regular" and if we aren't, a laxative is the answer. The plain medical truth is that any healthy person who eats a well-balanced diet, gets an adequate amount of exercise, and takes adequate fluids will probably never need a laxative. One might review several typical laxative ads with this in mind. In fact, laxatives can do more harm than good. Laxatives should never be used for a pain in the abdomen. The pain could be due to appendicitis and the laxative could actually cause the appendix to break and peritonitis to result.

It is important to remember that the digestive tract will function well if we:

(1) eat properly (amount, frequency, and kind of food);

(2) channel our emotions positively (love evidently has no bad side-effects on the digestive tract; anger certainly does);

(3) exercise regularly;

(4) use medication only when 1, 2, and 3 fail and then get professional counsel if the problem is frequent.

What are the similarities between infectious and serum hepatitis? The differences?

What is jaundice and how is it caused?

What symptom do gallstones and hepatitis often have in common?

What possible connection is there between gallstones and pancreatitis?

Vocabulary:

antibody (AN-tih-BAHD-ee)--a blood protein responsible for immunity.

bilirubin (BILL-ih-ROO-bin)--the main pigment of bile.

gallstone (GAWL-ston)--a mass of solid matter that may form in the gallbladder.

gastrointestinal tract--the stomach and the intestines (often abbreviated GI tract).

hepatitis (HEP-uh-TY-tis)--inflammation of the liver.

immune--the state of being protected against a specific disease.

jaundice (JAWN-dis)--yellowness of the skin due to excess bilirubin.

pancreatitis (PAN-kree-uh-TY-tis)--inflammation of the pancreas.

serum (SEER-um)--blood after cells and other proteins have been removed; the clear portion of blood.

REVIEW SET 9:

1. In what manner has man's method of obtaining food changed through the centuries?

2. What evidence is there for linking diet with heart disease?

3. What is the function of digestion?

4. Name the parts of the digestive system through which food passes.

5. What is an enzyme? How are enzymes related to digestion?

6. If a person lacked teeth, what effect would this have on the digestion of foods? How must a toothless person prepare food for digestion?

7. How is the stomach protected from its secretions of hydrochloric acid?

8. List the digestive functions of the liver, the gallbladder and the pancreas.

9. Through what structures in the small intestine are nutrients absorbed? How are these structures adapted for their important role in digestion?

10. What do we mean by epidemiological evidence? How does this differ from biological evidence?

11. How may salt affect health?

12. What is the role of the stomach in the digestive process?

13. Is there a relationship between gallstones and pancreatitis? Explain.

14. Which segment of the intestine is more critical to the digestive process, the small intestine or the large intestine? Why?

SECTION 10: ???

10-1 A Peculiar Liquid

What nutrient are we discussing?

Chemistry is the study of the properties and reactions of the millions of substances that either occur in nature or are made by man. If properties were unrelated to molecular structure, a chemist could never know about more than a small fraction of these substances. However, there are patterns that enable us to predict how a substance behaves by knowing the behavior of substances that are similar to it. The periodic table, as we saw in Unit I, is based on the relation between chemical properties and electron structure. Helium, neon, argon and krypton appear in the far-right column of the periodic table; all have filled electron shells and are chemically unreactive. The elements with greater atomic numbers are toward the bottom of the table; they are denser and generally solids at room temperature, while most of the gases are found toward the upper right-hand corner of the table.

Biological compounds may also be grouped by structure and chemical properties. We have already referred to such groupings in discussing fats, proteins and carbohydrates.

But in this section we consider a nutrient with unusual properties. It cannot be grouped with other compounds; it stands by itself. Generally we emphasize similarities in substances. What is interesting and important about this nutrient, however, is the ways in which it is different. As we discuss this mysterious nutrient, see whether you can guess its identity.

Consider, for example, boiling points. Among substances with covalent bonding, those with lower molecular weights (that is, lighter molecules) tend to exist as gases at lower temperatures. The following table gives the boiling points of some familiar substances, that is, the temperature at which the liquids (or solids) become gases.

Substance	Formula	Molecular weight, amu	Boiling point, °C
Hydrogen	H_2	2	-252.5
Methane	CH_4	16	-164.0
Nitrogen	N_2	28	-195.8
Oxygen	O_2	32	-183.0
Carbon dioxide	CO_2	44	-78.5
Ethyl alcohol	C_2H_6O	46	78.5
Acetone	C_3H_6O	58	56.2
Acetic acid	$C_2H_4O_2$	60	117.9
Octane (gasoline)	C_8H_{18}	114	125.7

Of the substances listed, those with molecular weights less than 45 amu are gases at room temperature (about 20 °C), while those with greater molecular weights are liquids. Our mysterious nutrient has a molecular weight of 18, so we would expect it to be a gas at room temperature. Based solely on the table, we might expect it to boil at a temperature less than -100 °C. However, it does not boil until it becomes much warmer than ordinary room temperature. The fact that this substance is a liquid at room temperature is of utmost importance not only to life, but to the appearance of our entire planet. Have you guessed what the mysterious nutrient is? Read on--more clues are coming.

Energy is required to increase the temperature of matter, but different quantities of energy are needed to raise the temperatures of different substances by a specific amount. The next table gives the number of calories required to raise the temperature of one gram of several familiar liquids by one Celsius degree.

Substance	Energy requirement to raise temperature, cal/g-°C
benzene	.406
acetic acid	.468
acetone	.528
ethyl ether	.547
octane	.578
ethyl alcohol	.581
methyl alcohol	.600

The energy required to raise the temperature of our peculiar nutrient by one Celsius degree, however, is 1.0 calorie per gram. This is about twice the energy needed in the cases of the other liquids. This property is also important to life.

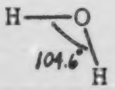
Perhaps the oddest property of this nutrient is seen so commonly that it is easily overlooked. It is the only familiar substance that is denser as a liquid than as a solid. This means that the solid form floats on the liquid.

The importance of this nutrient to mankind and all life is great--in fact it is essential. Historically, civilizations have risen and flourished only when this nutrient was readily available. Wars have been fought for access to it. One of the problems facing modern technology is to transport it to people living far from a source. Perhaps you have guessed the identity of the substance; its molecules contain two hydrogen atoms and one oxygen atom, and it is called water.

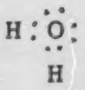
10-2 The Structure of Water

What is unusual about the structure of water?

The unusual properties of water are due to the shape of the molecule and the distribution of electric charge in the molecule. The hydrogen atoms are located such that the angle between bonds is 104.6°.



In Unit I, we described covalent bonding as the situation in which two atoms share a pair of electrons. The electron structure of water is represented as



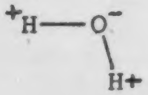
$$H:\overset{..}{\underset{..}{O}}: \atop \quad H$$

or

$$H:\overset{..}{\underset{..}{O}}:H$$

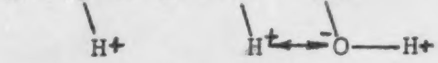
(Remember that the electron-dot formula does not represent the shape of the molecule.)

The unusual properties of water can be traced to the bonding between the oxygen and hydrogen. The bonding electrons are shared by oxygen and hydrogen atoms, but they are not shared equally. They are more attracted to the oxygen atom, and these electrons being near the oxygen give this atom a slightly negative charge. Since the electrons have been pulled away from the hydrogen, these atoms have a slight positive charge.



The situation is somewhere between (1) even sharing of a pair of electrons by oxygen and hydrogen, and (2) donation of an electron by hydrogen to oxygen. In other words, the nature of the bond is between a covalent and an ionic bond. A molecule that is positively charged in one part and negatively charged in another part is said to be polar.

Our study of electrostatics revealed that opposite charges attract one another. Negatively charged oxygen atoms attract positively charged hydrogen atoms of other molecules, so water molecules are drawn together.



This attraction between H atoms of one molecule and O atoms of other molecules is called hydrogen bonding. Hydrogen is the one element that forms this type of bond, because a positively charged hydrogen atom is just a proton; it is not surrounded by electrons like other elements. Hydrogen bonds are much weaker than normal covalent bonds, but they are strong enough to make a significant difference in the properties of water. Hydrogen bonding also occurs in other biological substances; for instance it is important in the structure of proteins.

10-3 Hydrogen Bonding and the Properties of Water

How does the structure of water explain its unusual properties?

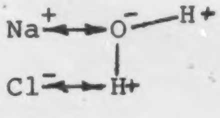
Let's consider how hydrogen bonding affects the properties of water. First of all, why isn't water a gas at room temperature?

A substance exists as a liquid or a solid rather than as a gas when the attraction between molecules (or ions) overcomes the particles' tendency to bounce off one another and move about rapidly. Hydrogen bonding between water molecules increases the attraction between molecules. For this reason H_2O is a liquid when we would expect it to be a gas, based on its molecular weight.

Why does it take so much heat (calories) to raise the temperature of water? You may recall (Unit I, Section 15-6) that when a gas is heated, the molecules move more repidly. Temperature is a measure of this motion. The molecules of liquids and solids also move faster when heated, but since the molecules are held together and cannot move very far, they vibrate more rapidly in a restricted space. Temperature is a measure of the speed with which they vibrate.

Hydrogen bonding makes it more difficult for water molecules to vibrate--they may be thought of as "stickier." Therefore, more energy is required to increase their speed of vibration. This explains why more calories are needed to raise the temperature of water than the other liquids we considered.

Another property of water that is important to living things is its ability to dissolve ionic substances. These substances must be dissolved in order to be absorbed and transported by the blood. This ability to dissolve substances can be explained by the polarity of water molecules. When sodium chloride is placed in water, the sodium ions, being positively charged, are attracted to the oxygen atoms of water, while negatively charged chloride ions are drawn toward the hydrogen atoms of water.



This causes the NaCl to dissociate into Na^+ and Cl^- ions.

How do these unusual properties of water affect life on this planet? Let's consider first the relatively large amount of energy required to heat water.

One calorie of energy from the sun falling on the ocean can raise the temperature of one gram of water by one Celsius degree. But the same calorie of energy can raise the temperature of one gram of other common liquids by about two degrees. If the oceans were filled with alcohol or ether, temperatures would vary between greater extremes. Since water absorbs energy with relatively little temperature increase, the temperature of the ocean does not fluctuate as greatly as the temperature of the land. (One calorie can heat one gram of rock about five Celsius degrees.) This is important to our climate and is why coastal areas do not experience the temperature extremes that are common inland.

Water serves the same function of moderating the temperature within our bodies. The heat generated during exercise tends to cause an increase in body temperature. But for many biological processes it is critical that the temperature be within a narrow range. For example, many enzymes do not function at temperatures slightly above body temperature. Also, heat is generated in many reactions in cells. If this heat were not absorbed by the large percentage of our bodies that is water, important enzymes would be inactivated and important body reactions would nearly stop. But water absorbs the heat, with an increase in temperature only about half the increase that would occur with most other liquids. Water contributes to the control of body temperature.

The functioning of our nervous system depends on the presence of potassium ions within the cells and sodium ions outside the cells (in the blood, for instance). If water were not a solvent for ionic substances, Na^+ and K^+ ions could not exist within our cells and body fluids. These and other important ions are available for various body functions because of the unusual properties of water. Such ions are available to us because, despite its relatively low molecular weight, water is a liquid; and water is so polar that it can dissolve ionic substances.

10-4 Water as a Nutrient

Why is water such an important nutrient?

Some people think they are "solid citizens," but they are mostly water. Everybody is. If you are a male in your late teens, sixty per cent of your body is water; if you are a female of the same age, the percentage is about 54 (since a larger proportion of your body is fat).

Water is an essential component of all cells. It is the medium in which most of the chemical reactions of the body occur. Water is required for regulation of the body's temperature, and it is also essential in lubricating the joints.

Water is obtained by the body not only from the water we drink, but from other liquids and solid foods as well. It is also obtained through chemical reactions in the body. When food reacts with oxygen to provide energy to the body, one product of the reaction is carbon dioxide. Another product is water.

food + oxygen → carbon dioxide + water

The average person requires between 1.5 and 2 liters of water daily, either as drinking water or in foods, to replace water which the body loses. There are four routes through which water is lost. One route is through the skin, as perspiration. Another is from the lungs. Water leaves the lungs through the nose and mouth as a vapor. (You have seen this vapor condensing on a cold morning.) A third route is through the kidneys, as urine, and the fourth is through the intestines, where water passes out in the feces.

The table below gives typical quantities of water which enter and leave a person's body during a day.

Water Intake	Volume (ml)
Liquids (water, coffee, soup, etc.)	1100
Solid foods	500 - 900
Water from chemical reactions in the body	400
	2000 - 2400

Water Losses	
Skin	520 - 600
Lungs	400
Urine	1000 - 1300
Feces	80 - 100
	2000 - 2400

Note that the amount of water taken in by the body is equal to the amount of water lost by the body. This balance is important to the body. If water loss increases through excessive sweating, diarrhea, vomiting or a kidney disease, more water must be consumed. In severe cases of untreated diabetes too much water is lost in the urine. Diabetics are often very thirsty--they drink a lot of water to compensate for the excessive loss in the urine. Sometimes the excessive thirst of diabetics prompts them to have a a medical examination which, in turn, leads to a diagnosis.

Water balance is important to the proper functioning of many systems of the body. It is important because the functioning of these systems depends on the concentration of various ions. Positive ions found in the body fluids include sodium (Na^+), potassium (K^+), calcium (Ca^{+2}) and magnesium (Mg^{+2}). Negative ions include chloride (Cl^-), bicarbonate (HCO_3^-), phosphate (PO_4^{-3}) and sulfate (SO_4^{-2}). If the water balance of the body changes, the concentrations of these electrolytes change, and the systems that use the electrolytes cannot function properly.

10-5 Nutritional Chemistry

Why is chemistry of special importance in the study of nutrition?

Water stands alone as a nutrient because of its unique set of properties. However, most nutrients have similar properties to other nutrients. We take advantage of these similarities by placing nutrients into five groups, as we did when discussing digestion in the first sequence of this unit. The five groups are carbohydrates, fats, proteins, vitamins and minerals. The division into groups is made according to the ways in which nutrients are digested and the ways in which they are used in the body.

Digestion takes place by a series of chemical reactions, and the body uses the products of digestion in further chemical reactions. The products of the digestion of carbohydrates, fats and proteins take part in chemical reactions that provide energy to the body. Bone and tissue are built from proteins and minerals by chemical reactions. Vitamins and certain minerals must be present for many of these and other reactions to occur. Therefore, a knowledge of chemical properties of nutrients is essential to an understanding of nutrition.

The chemical properties of a substance reflect the arrangement of atoms within the molecules of the substance. Thus we find that all carbohydrates have similarities in their molecular structures, as do all fats and all proteins.

Vitamins differ from minerals in that vitamins contain the element carbon, while minerals do not. Carbohydrates, fats and proteins also contain carbon. The chemistry of compounds containing carbon is so important, especially to biology, that it is considered to be a separate branch of the subject, called organic chemistry. Compounds, such as vitamins, carbohydrates, fats and proteins, that contain carbon are said to be organic, while substances that do not contain carbon, minerals for example, are called inorganic.

Since chemistry is so fundamental to an understanding of nutrition, and since so many nutrients are compounds containing carbon, organic chemistry is introduced in the next section. After discussing organic chemistry in somewhat general terms, we will proceed to specific nutrients in subsequent sections.

What is the general relation between molecular weight and boiling point? How does water fit into this pattern?

What is unusual about the amount of energy required to raise the temperature of one gram of water by one Celsius degree?

Describe the shape of a water molecule and the distribution of charge in a water molecule. What is meant by hydrogen bonding?

How does the structure of water help explain its unusual physical properties? (Consider density, boiling point, solvent action.)

Can you think of any biological implications of the fact that water is denser as a liquid than as a solid?

What are the body's sources of water? How does the body lose water?

Why do our bodies need water? Mention several biological functions of water.

What is the difference between organic chemistry and inorganic chemistry?

Vocabulary:

hydrogen bonding--the attraction between a hydrogen atom with a slight positive charge and an atom in another molecule that has a slight negative charge.

inorganic--relating to substances that do not contain carbon.

organic--relating to substances that contain carbon.

polar molecule--a molecule in which bonding electrons are not shared equally between atoms.

SECTION 11: HYDROCARBONS AND ALCOHOLS

11-1 Organic Chemistry

Are chemical reactions in the body different from those in test tubes?

It was once thought that there were two separate classes of substances. Non-living things, such as rocks, earth, air and water, were composed of one type of substance. These were called inorganic substances. Plants and animals were thought to be composed of another type of substance, said to be organic. Steel is inorganic, wood is organic.

It was supposed that organic compounds could be formed only by chemical reactions that occurred within living matter. A "vital force" was thought to be necessary to create organic substances. Steel can be made in a steel mill, but wood grows only in trees. Then in 1828 a German chemist named Friedrich Wohler made urea, an organic substance, in the laboratory. He made urea from ammonium cyanate, which is an inorganic substance; and chemists had to reconsider their ideas about inorganic and organic compounds and about the "vital force."

Today it is recognized that the chemical reactions that occur in the body are not different from those that occur in a test tube. However, it is useful to divide chemistry into inorganic chemistry and organic chemistry. Organic chemistry is no longer defined as the chemistry of living systems, but as the chemistry of compounds containing carbon. (A few simple carbon compounds such as carbon monoxide, carbon dioxide and carbonate salts are usually excluded, however.) Organic substances include proteins, fats, carbohydrates and vitamins, as well as most other compounds synthesized in the body. Nearly all of the chemical reactions occurring in our bodies involve organic chemicals. For these reasons the study of organic chemistry is basic to an understanding of nutrition and also to an understanding of most other processes within the body. We begin with a group of compounds that are simpler than other organic compounds in the sense that they contain only two elements, carbon and hydrogen.

11-2 Hydrocarbons

What is the structure of hydrocarbons? What are isomers?

The atomic number of carbon is 6. This means that a neutral carbon atom contains six electrons, two in the first shell and four in the second shell. It is the four electrons in the second shell that are involved in the chemical reactions of carbon. We may represent the carbon atom by its electron-dot formula.

$$\cdot\overset{\cdot}{\underset{\cdot}{C}}\cdot$$

An atom forms a covalent bond by sharing unpaired electrons with other atoms; carbon can share four electrons and thus form four bonds.

A hydrogen atom has one electron.

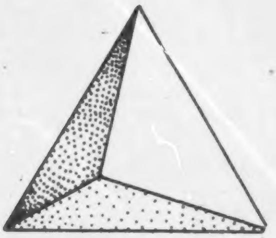
$$H\cdot$$

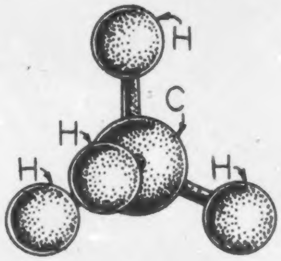
A carbon atom may form bonds with four hydrogen atoms by sharing its electrons and the electrons of the hydrogen atoms.

$$\begin{array}{ccc} & H & \\ & \cdot\cdot & \\ H\,: & C & :\,H \\ & \cdot\cdot & \\ & H & \end{array}$$

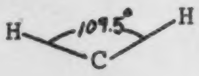
The formula of the resulting compound is CH_4, and it is called methane.

The four hydrogen atoms, however, are not in the same plane. Rather each is at the corner of a tetrahedron. A tetrahedron is a solid figure with four faces. Each face consists of a triangle with three equal sides. The carbon atom is at the center of the tetrahedron.



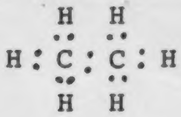


The angle between two carbon-hydrogen bonds is not 90° as the electron-dot formula would indicate, but approximately 109.5°.



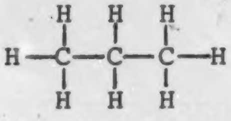
The angle 109.5° is often called the tetrahedral bond angle. The shape represented by the electron-dot formula cannot be correct because it does not show each hydrogen atom equally distant from every other one. Keep in mind that an electron-dot formula cannot give the actual shape of a molecule, because it represents a three-dimensional object in only two dimensions.

Another compound containing only carbon and hydrogen is ethane (C_2H_6).



Note that each C is bonded to four other atoms; each H has one bond. Again, the shape of an ethane molecule is not shown by the formula; the angles between bonds are approximately 109.5°.

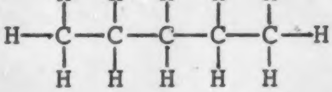
Many organic compounds consist of carbon atoms bonded to other carbon atoms by single bonds. The molecule which consists of a chain of three carbon atoms, which are also bonded to eight hydrogen atoms, is called propane. The structural formula for propane is



Compounds containing only hydrogen and carbon are called hydrocarbons. Methane, ethane and propane are examples of hydrocarbons.

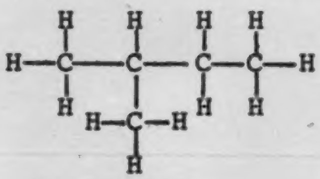
Carbon atoms have a great tendency to form chains by bonding to one another. Thus many compounds contain long chains of carbon atoms. These carbon chains are the backbone of organic chemistry and the reason why over a million different organic compounds exist.

The carbon atoms may be in a chain, or they may form molecules of other shapes. Five carbon atoms, for instance, may form the "straight-chain" compound pentane or normal-pentane (C_5H_{12}).

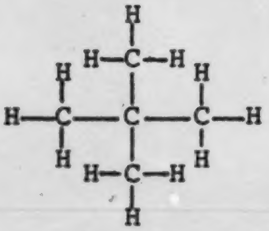


NORMAL-PENTANE

(Remember that the two-dimensional structural formula does not show the true shape of the molecule. The pentane chain isn't really straight, but zig-zag shaped.) Five carbon atoms may also form a compound with branches on the chain.



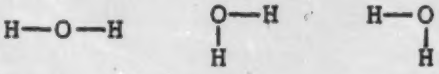
ISOPENTANE



NEOPENTANE

Isopentane and neopentane also have the formula C_5H_{12}. Normal-pentane, isopentane and neopentane are called isomers. Compounds are said to be isomers if they have the same molecular formulas, but different structures.* Normal-pentane, isopentane and neopentane all have the molecular formula C_5H_{12}, but their structures are not the same. When we say that their structures are different, we mean that atoms are not bonded to each other in the same arrangement. Thus, two of the five carbons in normal-pentane are bonded to only one other carbon. These two carbons are also surrounded by three hydrogens. Each of the other three carbons of normal-pentane is bonded to two carbons and two hydrogens. In isopentane, however, three of the five carbons are bonded to another carbon and three hydrogens. One is bonded to two carbons and two hydrogens, and the fifth carbon is joined to three carbons and just one hydrogen. In neopentane, one carbon is bonded to all of the other four carbons.

Be sure you do not confuse this situation with the fact that the same structure may be drawn in different ways. For instance, water can be shown in the following ways.



$$\mathrm{H{-}O{-}H} \qquad \begin{array}{l}\mathrm{O{-}H}\\ \mathrm{|}\\ \mathrm{H}\end{array} \qquad \begin{array}{r}\mathrm{H{-}O}\\ \mathrm{|}\\ \mathrm{H}\end{array}$$

These structures all represent the same molecule, and do not represent isomers. In every one an oxygen atom is bonded to two hydrogen atoms.

Isomers are encountered often in organic chemistry. The physical and chemical properties of a pair of isomers may be very different. The idea of isomers is important to our study of nutrition because our bodies are able to distinguish differences in structure, and often a particular isomer is needed for our survival. You may recall that enzymes are selective in the substrates upon which they act. Often an enzyme will act only on one of a group of isomers.

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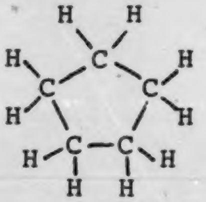
* You may recall that two isotopes have the same number of protons, but different numbers of neutrons.

Five carbon atoms may be (1) in a chain, as they are in normal-pentane; (2) they may have branches on the chain, as in isopentane or neopentane; or (3) they may form a ring (cycle). The structural formula of a compound which has five carbons in a ring is shown below.



CYCLOPENTANE

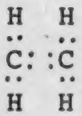
This particular compound is known as cyclopentane; hydrocarbons containing rings are said to be cyclic hydrocarbons. (Cyclopentane is not an isomer of normal-pentane; it has two fewer hydrogens.)

The occurrence of branches and rings increases greatly the number of possible organic compounds.

11-3 Double and Triple-Bonded Organic Compounds

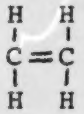
What is an unsaturated hydrocarbon?

In the Respiration Unit (Section 24-1) we introduced the idea of double and triple bonds. We considered a hydrocarbon with a double bond called ethylene (C_2H_4). Its molecular structure can be represented by the following electron-dot formula.



ETHYLENE

Each carbon atom contributes two of its electrons to the double bond, as well as one to each of the bonds with hydrogen atoms. Ethylene may also be represented by the structural formula,



The double bond is represented by two lines.

Acetylene, C_2H_2, is a hydrocarbon which contains a triple bond. Each carbon atom contributes three electrons to the triple bond.

$$H:C\vdots\vdots C:H$$

The triple bond is represented in a structural formula by three lines.

$$H-C\equiv C-H$$

Organic compounds with no double or triple bonds between carbon atoms are said to be saturated. Organic compounds with at least one double or triple bond between carbons are called unsaturated. Methane, ethane and propane are saturated, while ethylene and acetylene are unsaturated. The concept of saturated and unsaturated compounds will be useful when we discuss the relation between fats and health.

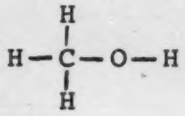
Hydrocarbons do not react with most substances as readily as other organic compounds, and they are not used by our bodies as nutrients. There is, however, one type of reaction that hydrocarbons take part in readily. This type of reaction is oxidation, and the reaction of hydrocarbons with oxygen makes them useful to us as fuels. Natural gas is mainly methane, with smaller amounts of ethane and propane. Petroleum is a mixture of hydrocarbons with higher molecular weights and thus higher boiling points than natural gas components. So, although our bodies are unable to digest and make use of hydrocarbons internally, they are important sources of energy externally.

11-4 Alcohols

What is a functional group? What is the functional group in alcohols?

Hydrocarbons contain only carbon and hydrogen, but most organic compounds contain other elements as well. Carbohydrates, fats and proteins contain oxygen in addition to carbon and hydrogen; proteins also contain nitrogen and sulfur. Hydrocarbons contain fewer elements than other organic substances, but there is another reason for starting with hydrocarbons. The reason is that the names of many other organic compounds are based on the names of hydrocarbons.

For example, the compound with the following structural formula is called methyl alcohol (or methanol).

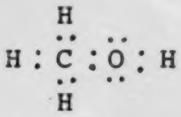


$$\begin{array}{c} \phantom{H-{}}H \\ \phantom{H-{}}| \\ H-C-O-H \\ \phantom{H-{}}| \\ \phantom{H-{}}H \end{array}$$

One hydrogen atom in the structural formula of methane is replaced by an oxygen atom joined to a hydrogen atom. The combination of an oxygen atom and a hydrogen atom is known as a hydroxyl group. When methyl alcohol reacts, usually the hydroxyl group is involved in the reaction.

The hydroxyl group is a typical functional group. A functional group is a portion of an organic molecule that tends to take part in chemical reactions. We have previously written the formula of methyl alcohol as CH_4O, but it is also commonly written CH_3OH in order to indicate the hydroxyl group.

Note that the oxygen atom has formed two bonds. An oxygen atom has six electrons in its outer shell, and needs two to complete the shell. The oxygen atom and the carbon atom share electrons and form a bond; the oxygen atom also shares electrons with a hydrogen atom to form another bond. The electron-dot formula of methyl alcohol is

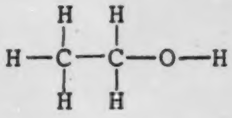


$$\begin{array}{ccccccc} & & \mathrm{H} & & & & \\ \mathrm{H} & : & \overset{..}{\underset{..}{\mathrm{C}}} & : & \overset{..}{\underset{..}{\mathrm{O}}} & : & \mathrm{H} \\ & & \mathrm{H} & & & & \end{array}$$

All oxygen atoms in the compounds we will consider have two bonds, just as all carbon atoms have four bonds and all hydrogen atoms have one bond.

Note how methyl alcohol is named as though it is made up of two parts, a methyl (or methane) part and an alcohol (or hydroxyl) part. The hydroxyl group may be represented by the formula -OH. The dash indicates that the group is not a complete molecule, but that a bond is formed between the oxygen and another atom. The dash does not indicate negative charge, and a hydroxyl group is not the same as a hydroxide ion. A hydroxide ion exists as a separate entity with a negative charge and is represented as OH^-. The -OH group is part of a larger molecule and is not charged as an ion is.

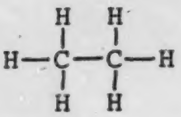
Methyl alcohol is one of a class of compounds that contain hydroxyl groups. These substances are called alcohols. Another example is ethyl alcohol (or ethanol). It has also been called grain alcohol and is the type in alcoholic beverages. The structural formula of ethyl alcohol is



$$\begin{array}{ccccccccc} & & \mathrm{H} & & \mathrm{H} & & & & \\ & & | & & | & & & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{O} & - & \mathrm{H} \\ & & | & & | & & & & \\ & & \mathrm{H} & & \mathrm{H} & & & & \end{array}$$

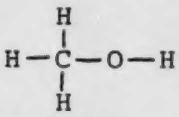
ETHYL ALCOHOL

Compare ethyl alcohol to ethane and to methyl alcohol.



$$\begin{array}{ccccccc} & & \mathrm{H} & & \mathrm{H} & & \\ & & | & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{H} \\ & & | & & | & & \\ & & \mathrm{H} & & \mathrm{H} & & \end{array}$$

ETHANE

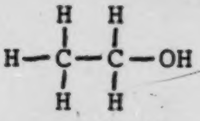


$$\begin{array}{ccccccc} & & \mathrm{H} & & & & \\ & & | & & & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{O} & - & \mathrm{H} \\ & & | & & & & \\ & & \mathrm{H} & & & & \end{array}$$

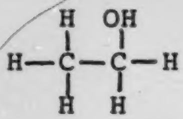
METHYL ALCOHOL

The structure of ethyl alcohol is the same as the structure of ethane except that one hydrogen of ethane is replaced in ethyl alcohol by a hydroxyl group.

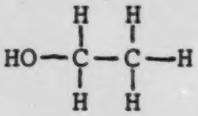
Structural formulas are often simplified slightly by writing the functional group as a unit, by representing a hydroxyl group either as -OH or HO-. All of the following structural formulas are equivalent representations of ethyl alcohol. (Remember that the atoms do not all lie in one plane, as they do in the formula, and that the angles between bonds are not 90°, as shown, but actually about 109°. The equivalence of the representations may be more easily seen by using a molecular model.)



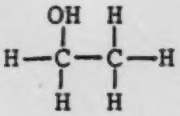
$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-OH}$



$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{OH}{\underset{H}{C}}-H}$



$\mathrm{HO-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H}$

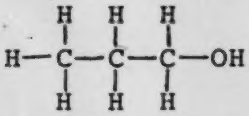


$\mathrm{H-\overset{OH}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H}$

The molecular formula of ethyl alcohol is C_2H_6O, or C_2H_5OH if the hydroxyl group is to be shown.

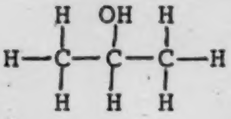
The hydroxyl group is important because it is the portion of the molecule that takes part in most chemical reactions. The carbon chain itself and the attached hydrogen atoms are relatively resistant to reaction, but the hydroxyl group takes part in a variety of reactions. The reactions are characteristic of an -OH group, whether it is part of a methyl alcohol molecule, an ethyl alcohol molecule or some other alcohol. We will see that more complex carbohydrates are built from simpler ones by the reaction of a hydroxyl group, and that fats are built from their components by hydroxyl groups reacting.

If one hydrogen atom of a propane molecule is replaced with a hydroxyl group, the compound is called propyl alcohol. Two propyl alcohol isomers exist. One has the -OH group attached to a carbon at the end of the chain and is called normal-propyl alcohol, or simply propyl alcohol.



$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-OH}$

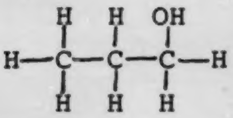
In the case of the other isomer, the hydroxyl group is bonded to the middle carbon atom. This isomer is called isopropyl alcohol.



$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{OH}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H}$

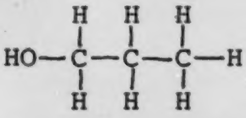
Isopropyl alcohol is used as rubbing alcohol.

It is important to understand that these are the only possible isomers of propyl alcohol. Other formulas that may be drawn, such as the following, represent isopropyl alcohol if the hydroxyl group is attached to the middle carbon, or normal-propyl alcohol if the -OH is attached to an outer carbon.



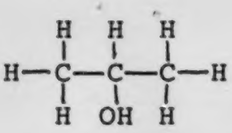
$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{OH}{\underset{H}{C}}-H}$

NORMAL-PROPYL
ALCOHOL



$\mathrm{HO-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H}$

NORMAL-PROPYL
ALCOHOL



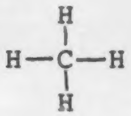
$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{OH}{C}}-\overset{H}{\underset{H}{C}}-H}$

ISOPROPYL
ALCOHOL

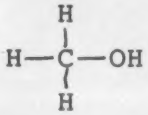
The scheme used for naming many of the organic compounds we will encounter is illustrated by the names of the alcohols we have considered. The first part of the name indicates the number of carbon atoms in the chain. The second part of the name indicates the functional group.

HYDROCARBONS

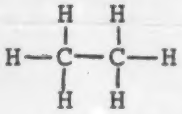
ALCOHOLS


$H-\overset{H}{\underset{H}{C}}-H$

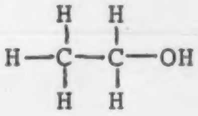
METHANE


$H-\overset{H}{\underset{H}{C}}-OH$

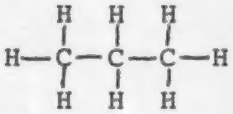
METHYL ALCOHOL


$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H$

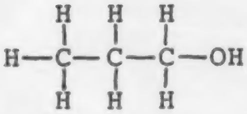
ETHANE


$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-OH$

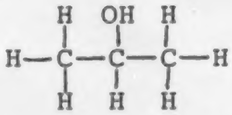
ETHYL ALCOHOL


$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H$

PROPANE


$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-OH$

PROPYL ALCOHOL


$H-\overset{H}{\underset{H}{C}}-\overset{OH}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H$

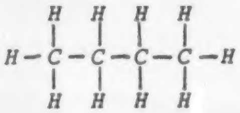
ISOPROPYL ALCOHOL

Most alcohols are toxic and have no place in nutrition, but the hydroxyl group has an important part in the chemistry of carbohydrates and fats, as we will see.

What element do all organic compounds contain?

What elements do hydrocarbons contain?

In what way is a structural formula misleading?

What is meant by an isomer? Draw an isomer of  $H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H$ *(normal butane).*

Do isomers have identical physical and chemical properties?

What is the difference between a saturated hydrocarbon and an unsaturated hydrocarbon?

What functional group is part of all alcohols?

The structure of pentane is shown in the text. How many carbons would pentyl alcohol have?

Vocabulary:

alcohols--a class of organic compounds having one or more -OH groups.

functional group--a reactive part of an organic molecule.

hydrocarbon--a compound containing only the elements carbon and hydrogen.

hydroxyl group (hy-DROX-ul)--a functional group consisting of one hydrogen and one oxygen atom (-OH).

isomer (EYE-suh-mur)--one of two or more substances with the same molecular formula but different structures.

saturated--describing an organic compound having only single bonds between carbons.

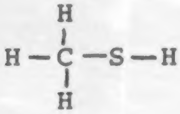
unsaturated--describing an organic compound having at least one double or triple bond between carbons.

PROBLEM SET 11: . .

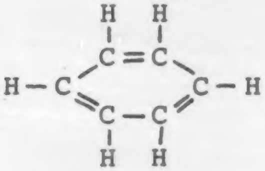
1. Which of the following compounds are organic and which are inorganic?

a. H_2O

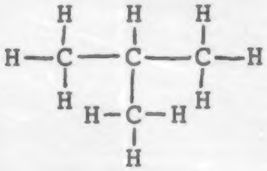
c. CH_3OH

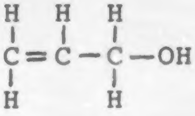
b. 

$H-\overset{H}{\underset{H}{C}}-S-H$

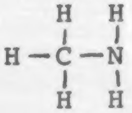
d. 

2. Which of the following compounds are hydrocarbons, which are alcohols and which are neither?

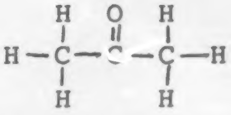
a. 

c. 

$\overset{H}{\underset{H}{C}}=\overset{H}{C}-\overset{H}{\underset{H}{C}}-OH$

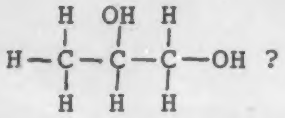
b. 

$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{N}}$

d. 

$H-\overset{H}{\underset{H}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{\underset{H}{C}}-H$

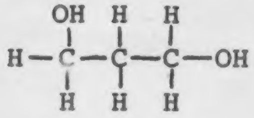
3. Which of the following representations are equivalent to



$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{OH}{C}}-\underset{H}{\overset{H}{C}}-OH$?

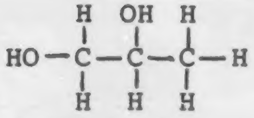
Which ones represent isomers of the above compound?

a.



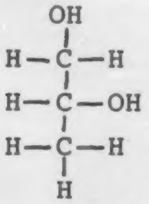
$H-\underset{H}{\overset{OH}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-OH$

b.

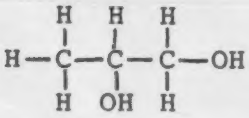


$HO-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{OH}{C}}-\underset{H}{\overset{H}{C}}-H$

c.



d.



$H-\underset{H}{\overset{H}{C}}-\underset{OH}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-OH$

4. Which compounds in Problems 1 through 3 are unsaturated?

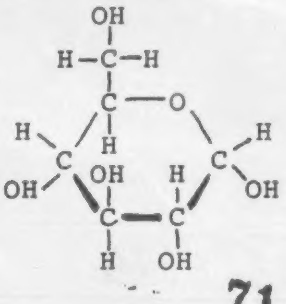
SECTION 12: CARBOHYDRATES

12-1 Carbohydrate Chemistry

What are the structures of the simplest carbohydrates?

Proteins, fats and carbohydrates are the three groups of nutrients that provide us with energy (calories). Each of these three groups includes many different substances, but each substance has chemical properties characteristic of its group. The substances in each group are digested by similar processes, and are needed for the same kinds of functions in the body. A substance can be identified as a protein, fat or carbohydrate by certain characteristics of its structural formula.

Carbohydrates are composed of carbon, hydrogen and oxygen. The simplest carbohydrates are monosaccharides ("mono-" indicating "one;" "saccharide" from the Latin word for sugar). The monosaccharide with the most important role in nutrition is glucose. The molecular formula of glucose is $C_6H_{12}O_6$. The structural formula is

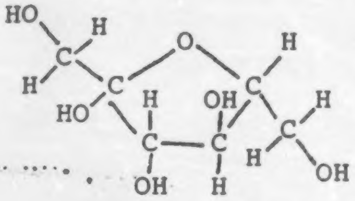


GLUCOSE
($C_6H_{12}O_6$)

Five carbon atoms and one oxygen atom are arranged in a ring. The sixth carbon is attached to one of the carbons in the ring. Carbohydrates contain hydroxyl (-OH) groups. A glucose molecule contains five hydroxyl groups, each attached to a different carbon.

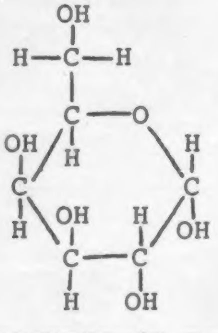
We have shown glucose in a special way to help you visualize the shape of the molecule. Picture the ring as being perpendicular to the page. The atoms connected by bonds with thick lines are to be pictured as if they are in front of the page. The -H and -OH groups are above or below the plane of the ring. Drawing a group above a carbon is not equivalent to drawing the group below the carbon ring, as it is in, say, ethyl alcohol. A molecular model of C_2H_5OH may be rotated or twisted until all the equivalent representations are seen (see Section 11-3). To transfer a hydroxyl group from below the ring to above the ring, however, requires breaking bonds and forming new ones.

Two other monosaccharides are isomers of glucose. They are fructose and galactose; each has the molecular formula $C_6H_{12}O_6$, just as glucose does. Their structural formulas are shown below.



FRUCTOSE ($C_6H_{12}O_6$)

Fructose has the same molecular formula as glucose but differs from glucose in that only four carbons, rather than five, and one oxygen form the ring. The other two carbons are outside the ring. Fructose occurs in many fruits, and honey is roughly half fructose and half glucose. Fructose is the sweetest tasting of the various carbohydrates in our diets.



GALACTOSE ($C_6H_{12}O_6$)

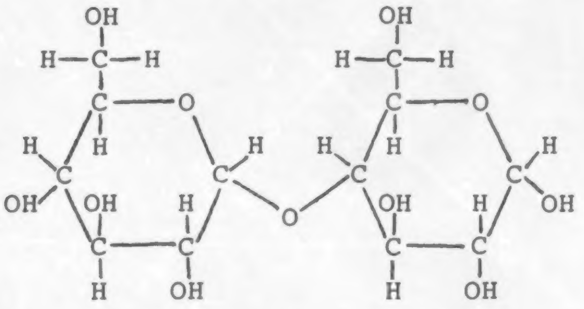
A galactose molecule has the same number of carbons, hydrogens and oxygens as a glucose molecule and is very similar in structure to glucose. It differs only in the position of the -H and -OH on the left-most carbon. In the structural formula of glucose, the hydrogen is above this carbon, while the hydroxyl group is below. In the galactose formula, by contrast, the H is below the C and the OH above. This slight difference gives galactose a different structure than glucose; if you make a molecular model of one, you can see that its structure cannot be converted to the structure of the other without breaking and reforming bonds. Thus glucose and galactose are isomers and are treated as different substances by the enzymes of the body.

Monosaccharides occur naturally, as in fruits and honey, but they are more often found as part of complex carbohydrates. These substances, to which we now turn our attention, are built from the three monosaccharide rings just discussed.

12-2 Dissaccharides and Polysaccharides

How are monosaccharides combined to form disaccharides and polysaccharides?

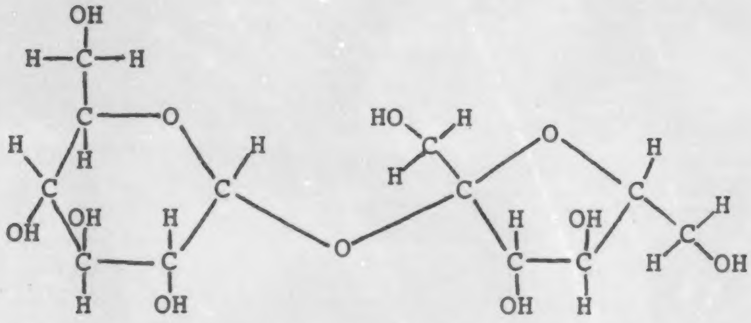
Maltose is a sugar found in grains and malts. Its molecular formula is $C_{12}H_{22}O_{11}$. The structural formula of maltose is shown below.



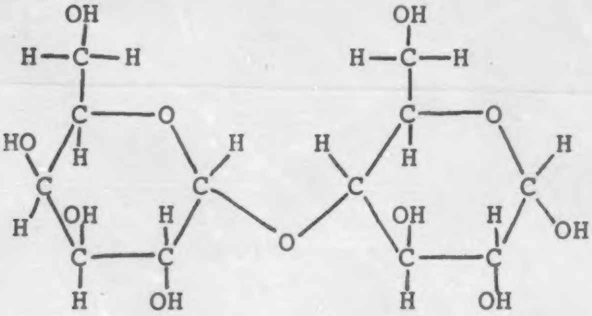
MALTOSE ($C_{12}H_{22}O_{11}$)

Look closely at the structure of maltose. Compare it to the structural formula of glucose. A maltose molecule is two glucose molecules joined together, with two hydrogen atoms and an oxygen atom (a water molecule) missing. Maltose is an example of a disaccharide, a compound with two monosaccharide rings.

The other important disaccharides (which are isomers of maltose) are sucrose (ordinary table sugar) and lactose (milk sugar). Sucrose and lactose are isomers, but we can distinguish between them by taste. Sucrose tastes much sweeter than lactose. The structural formulas of sucrose and lactose are shown on the following page. A sucrose molecule is formed by the combination of a glucose molecule and a fructose molecule. Lactose is formed from galactose and glucose. In both reactions water is eliminated as a by-product.



SUCROSE ($C_{12}H_{22}O_{11}$)

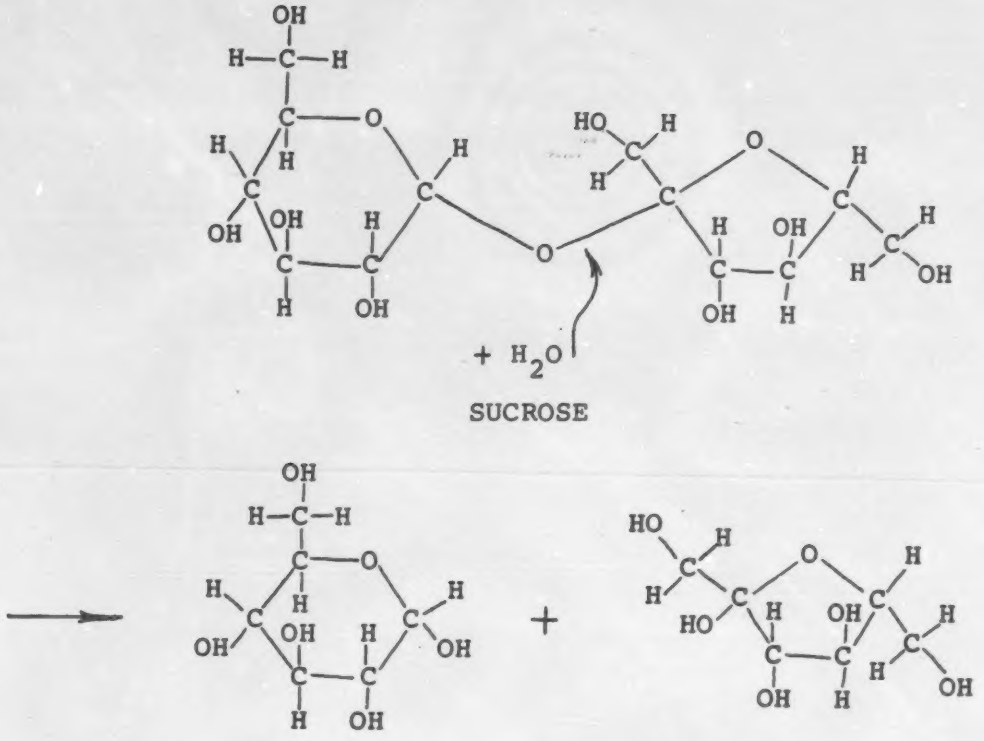


LACTOSE ($C_{12}H_{22}O_{11}$)

The reverse reaction, in which a disaccharide is divided into two monosaccharides, is of great importance biologically. Substances are useful to the body only if they are soluble and diffuse easily; large molecules tend to be insoluble and because of their size do not diffuse as rapidly as smaller molecules. Monosaccharide molecules are smaller than disaccharide molecules, dissolve more readily, are absorbed more easily into the body and diffuse more easily within the body.

Under certain conditions, including the presence of specific enzymes, disaccharides take part in a type of reaction called hydrolysis. A hydrolysis is a reaction in which a water molecule reacts with another molecule, causing the other molecule to split into smaller molecules. (In fact, the word "lysis" means "disintegration.") Reactions involving hydrolysis (hydrolytic reactions) are very important in digestion. Much of the breakdown of proteins, carbohydrates and fats is the result of hydrolytic reactions.

In the hydrolysis of a disaccharide the water molecule adds at the point where the two monosaccharides are joined together. The result is that the dissaccharide splits into two monosaccharides. The hydrolysis of sucrose to glucose and fructose is illustrated on the following page. The encircled H and OH are those from the H_2O.



SUCROSE

GLUCOSE

FRUCTOSE

In a similar fashion maltose hydrolyzes to glucose, and lactose hydrolyzes to glucose and galactose.

maltose + water → glucose + glucose

lactose + water → glucose + galactose

Monosaccharides and disaccharides are collectively known as sugars. A compound with many monosaccharide rings joined together is called a polysaccharide ("poly-" means many). Polysaccharides are digested by breaking the long chains of monosaccharides down to smaller chains. The only polysaccharide that occurs in significant quantities in foods, and that we can digest, is starch. A starch molecule consists of a large number of glucose molecules linked together. We have an enzyme (amylase) that is able to break starch down to glucose by a series of hydrolytic reactions.

Many foods contain the polysaccharide cellulose, which is a main component of wood and paper. However, our bodies lack the enzyme (cellulase) to break down cellulose, so we cannot use it as a nutrient. Termites possess that enzyme and consequently are rough on wood-frame houses.

Another polysaccharide, called glycogen, occurs only in small quantities in foods, but is nevertheless important in nutrition. The body stores carbohydrates in the form of glycogen, which it synthesizes from glucose that has been digested. The process is reversible and glycogen can be converted to glucose as needed.

To sum up, carbohydrates may be grouped into three categories: monosaccharides, disaccharides and polysaccharides. The examples we have discussed include the following molecules:

Monosaccharides	Disaccharides	Polysaccharides
glucose	maltose (malt sugar)	starch
fructose	sucrose (table sugar)	glycogen
galactose	lactose (milk sugar)	cellulose

Which elements are contained in carbohydrates?

What is the difference, if any, between carbohydrates and hydrocarbons?

Which of the following are pairs of isomers?

glucose and fructose
glucose and maltose
glucose and sucrose
maltose and sucrose

What is hydrolysis? Why is it important in digestion?

Vocabulary:

disaccharide (dy-SAK-uh-ride)--a carbohydrate consisting of two monosaccharide rings.

hydrolysis (hy-DRAHL-uh-sis)--a reaction in which a molecule is split by combining with water.

monosaccharide (MON-o-SAK-uh-ride)--a carbohydrate usually containing five or six carbons; the building block of polysaccharides.

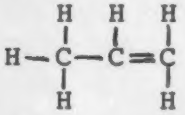
polysaccharide (PAHL-ee-SAK-uh-ride)--a carbohydrate containing many smaller units.

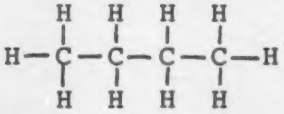
sugar--any monosaccharide or disaccharide.

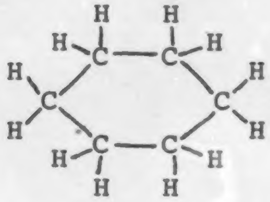
PROBLEM SET 12:

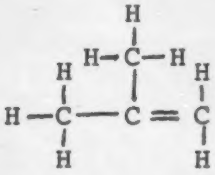
1. What elements are found in
   a. a hydrocarbon?
   b. an alcohol?

2. Which of the following hydrocarbons are saturated and which are unsaturated?

a. 
$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{C}=\overset{H}{\underset{H}{C}}}$

c. 
$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H}$

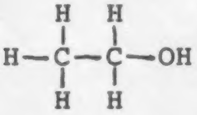
b. 

d. 

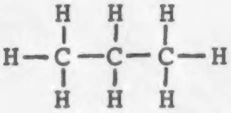
3. a. What is the functional group of an alcohol?

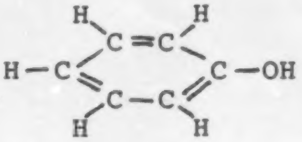
b. What is the structural formula of this functional group?

4. Which of the following substances are alcohols?

a. 
$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-OH}$

c. CH_3OH

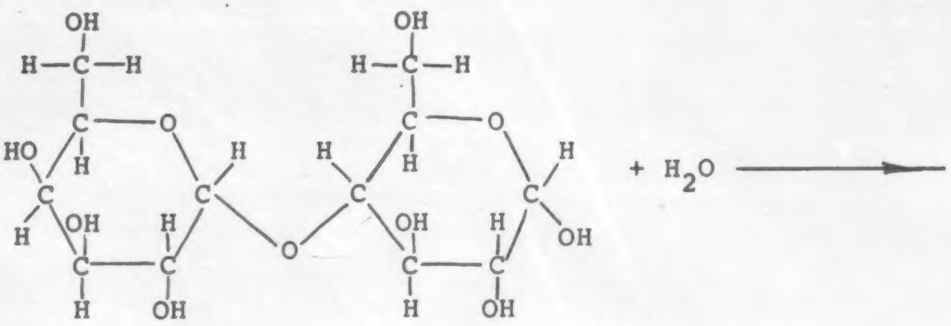
b. 
$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H}$

d. 

5. Draw the structural formula of a substance with the formula C_6H_{14} (hexane).

6. Draw the structural formula of as many isomers as you can of your structure for Problem 5.

7. Complete the following equation for the hydrolysis of lactose.



SECTION 13: CARBOHYDRATES IN THE DIET

Is sugar desirable in a diet?

Is there a connection between sugar and heart disease?

We have seen that carbohydrates are digested by being broken down (hydrolyzed) to monosaccharides. Starch, a long-chain polysaccharide, is hydrolyzed to glucose, while various disaccharides are hydrolyzed to glucose, fructose and galactose. Glucose is used by the cells of the body as a source of energy; fructose and galactose are converted to glucose, mostly in the liver.

Monosaccharides and disaccharides (sucrose, maltose and lactose) are collectively called sugars. Carbohydrates--starch and sugars--are the principal sources of energy in most diets. Foods that are mainly carbohydrate are generally less expensive than foods that are mostly protein and fat. Also, many vitamins and minerals are obtained from foods that are mostly carbohydrate.

Our bodies presumably became suited to obtaining a large percentage of our energy from carbohydrates through many generations of adapting to the available foods. But a trend has occurred in industrialized countries that our bodies are apparently not adapted to. People in some of the richer, more industrialized countries tend to consume a greater proportion of sugar and a smaller proportion of starch. This trend is causing health problems.

One problem is that our teeth are not adapted to being in contact with sugar. Sugars are used by bacteria in our mouths and converted to acids which cause tooth decay.

The trend toward sugars also has a nutritional disadvantage, caused by the refining of sugars. Carbohydrates naturally occur with substantial amounts of vitamins and minerals, and even small amounts of protein. But most sugar that is consumed is refined, and valuable nutrients are lost during refining. The table below compares the vitamin and mineral content of crude brown sugar, refined white sugar and brown rice, a typical food with a high starch content. Note that crude sugar is more nutritious than refined sugar.

	Minerals			Vitamins		
	mg Calcium	mg Phosphorus	mg Iron	mg Thiamin	mg Riboflavin	mg Niacin
100 g crude brown sugar	51	44	4.2	.02	.11	.3
100 g refined white sugar	5	1	.1	.00	.00	.0
100 g cooked brown rice	12	73	.5	.09	.02	1.4

Refined sugars provide energy, but smaller quantities of other nutrients than other carbohydrates provide. Thus the trend from starch to sugars is made worse by the fact that the trend is from starch to refined sugars.

There is also evidence that the replacement of starch by sugar in the diet may cause a more serious problem. It is a disease called atherosclerosis. In this disease, fats and other substances deposit in the walls of larger blood vessels over a long period of time and cause the inside of the vessels to become narrower. This narrowing restricts the flow of blood. In addition, there is a tendency for clots to form at these points which may totally stop the flow of blood. A clot in the vessels that supply the heart itself with blood may cause a heart attack. In fact, atherosclerosis is considered to be the underlying cause of almost all heart attacks.

Much of the evidence that dietary sugar is related to atherosclerosis is statistical. Statistical studies show a correlation between the sugar consumption in a country and the death rate from heart disease in that country. Such a correlation does not prove anything. However, it does suggest the possibility that sugar consumption could lead to heart attacks, and since heart attacks are such a frequent cause of death, the correlation indicates that this is a field in which research should be done.

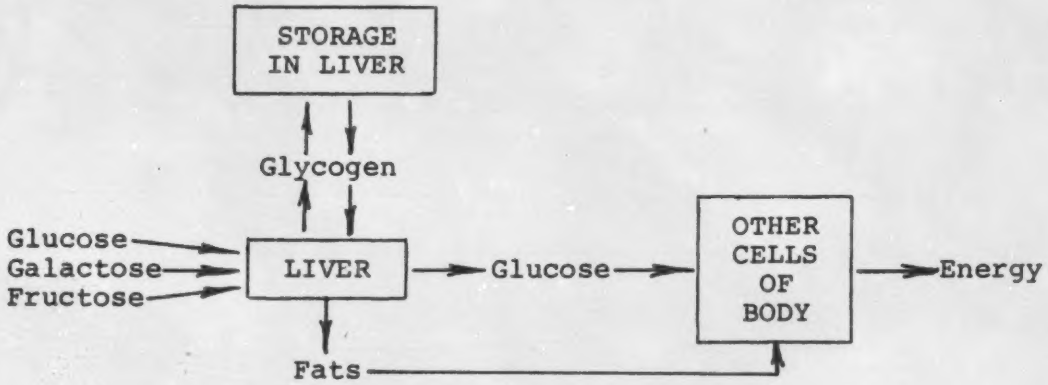
Research is being done to determine the relation between sugar and atherosclerosis, and much is yet unknown. However, we may construct an explanation based on what is known and what seems reasonable. Our explanation may be too simple, because enzymes and hormones may also be involved. As we explain the possible connection between sugar and atherosclerosis we will indicate what is fact and what is only a reasonable guess.

The first part of the explanation is based on what is known. It begins with the digestion of sugars, and the difference between sugar digestion and starch digestion. The products of the digestion of both sugars and starches are monosaccharides, but the rates of digestion are different. Hydrolyzing a starch chain into monosaccharides requires more time than splitting a disaccharide. And monosaccharides do not have to be chemically changed at all. In other words, sugars are digested much more rapidly than starches.

Because sugars are digested more rapidly than starches, they are absorbed into the blood in a shorter period of time. This rapid absorption temporarily results in a high concentration of glucose in the blood. To understand why this high concentration of glucose may cause a problem, we must consider what happens to it after it enters the blood.

Glucose is used by the body for energy, but if more glucose is available than the body immediately needs, it is converted in the liver to glycogen, which is stored for future use. If the body runs short of glucose, the liver can converte glycogen back to glucose and release it into the blood.

The liver has a limited capacity to store glycogen. When the liver has stored all the glycogen it can, any remaining excess glucose is converted to fats. The body stores fats and can use them as sources of energy when no glucose is available.



Conversion, storage and use of monosaccharides.

Since starch is digested more slowly than sugars, the glucose produced by starch hydrolysis is absorbed into the blood at a slower rate. If the body uses glucose at the rate it enters the blood, the concentration of glucose in the blood does not increase. The capacity of the liver to store glycogen is not exceeded, and no glucose is converted to fat.

Our discussion to this point is based on fact. The remainder, however, is only a hypothesis based on limited evidence; but it provides a reasonable explanation of one way in which sugar and heart disease could be related.

If the hypothesis is correct, the problem involves the conversion of glucose to fat that occurs when glucose enters the body faster than the body can use it. It has been found that the amount of fat in the blood can be decreased by reducing the amount of sugar in the diet. It has also been determined that the rate of development of atherosclerosis is partly related to the fat level in the blood. Thus we may speculate that increased sugar consumption causes more fat to be formed, and that while this fat is being transported in the blood, a small amount finds its way into the walls of the blood vessels. Remember that this possible connection is only theoretical. The fact that two things can happen in the body does not prove that one causes the other. But the problem of heart disease is an important one, and hopefully the research in progress will demonstrate whether a high sugar diet causes atherosclerosis.

There is another point worth mentioning. The traditional practice of eating dessert after a meal rather than before appears to be a good one. In the stomach the sugar from the dessert gets mixed in with the other foods that have been eaten. The result is that the sugar is digested more slowly. It is when sugar is eaten on an empty stomach, such as a candy bar at snack time, that large amounts of sugar enter the bloodstream quickly.

There is no minimum daily requirement for carbohydrates. The main function of carbohydrates in the diet is to provide sufficient calories. Carbohydrates could be eliminated from a diet (and replaced by other nutrients), but this is not desirable. Carbohydrates are inexpensive, easy to store and preserve and they add taste. There may be good reason, though, to keep the proportion of sugars to starches as low as possible. An ounce of rice may not be the same as a one-ounce candy bar from the standpoint of health.

Which nutrient is the principal energy source in our body?

Which are digested more rapidly, sugars or starches?

What does the body do with excess glucose?

Does sugar cause heart attacks? What evidence is there to support your answer?

Vocabulary:

atherosclerosis (ATH-ur-o-skle-ROW-sis)--a process that involves the deposit of fats and other substances in the walls of larger blood vessels and that results in a narrowing of the inside of the vessels.

SECTION 14: CASE HISTORY: HYPOGLYCEMIA

14-1 Case History--Male Aged 17

What was Coach Jones' secret weapon?

Last track meet of the year. The big one. The next event would be the 440, and the runners were huddled around the coach.

Any other coach would have been giving them a pep talk, reminding this man to keep his head up, that one to pace himself. But not Coach Jones. He didn't give them pep talks. He gave them honey.

Eldridge watched the jar going around the circle. He didn't particularly like the stuff, but there was no way to get out of eating it. You ate a third of a cup before your event, or you didn't run. Coach said it gave you lots of energy. Eldridge wasn't so sure.

After the last meet he'd told the coach he was afraid the honey was hurting more than helping. Running seemed to tire him out more than it used to, before the coach got on this kick. But Jones hadn't been impressed. "Maybe you just didn't get enough honey," he'd said.

Now the coach handed him his cup and poured in the honey. Eldridge made a face at it but he gulped it down.

2 "Yech!"

"Great stuff, isn't it?" said the coach.

"Terrible! It tastes like flowers."

"Orange blossom honey," said the coach. "Special treat for the big meet. How about a second helping?"

"Coach, I've got so much energy now I might not be able to wait for the gun. You better save it for the other guys."

The race went about as expected. Eldridge took second, which was no surprise. He almost took first, and that was a surprise.

After the race there were ceremonies, and Eldridge couldn't get anything to eat because he had to stand around and smile a lot and pay attention to the speeches.

About an hour after the race, Eldridge was bushed. The team captain came over and told him he was sweating harder now than he was when he crossed the finish line.

"I know, man," said Eldridge. "I just don't feel well at all."

"Flake out on the grass," said the captain. "You've been on your feet too long."

Eldridge lay down on the grass, glad to because he felt like he was going to faint. He wasn't breathing hard, but he was trembling all over.

"Get the doc, will you?" he said. "I'm sick."

The team doctor bent over Eldridge and looked him over. He wiped some of the sweat off his face and felt his forehead.

"The way you're shaking and sweating, looks like you've got a chill. But you're not especially warm. How do you feel?"

"Hungry," Eldridge managed to say.

The doctor nodded and then turned to one of the other runners standing around Eldridge.

"Get some food over here," he said. "Anything. Hurry up."

Eldridge put away a couple of hot dogs and a bag of soggy French fries. Ten minutes later he was on his feet again. The coach came over and asked him how he felt.

"Fine," said the runner. "Just fine."

"Looks to me like you should have taken that second helping of honey," said the coach.

Eldridge looked at him a moment.

"You know, Coach," he said, "I think I'll drop track and take up chess."

14-2 Hypoglycemia

Did the honey help or hurt Eldridge?

Because the body uses glucose directly for energy, it has mistakenly been thought that eating it is the best way to obtain energy quickly. Honey is about half glucose (the other half is mostly fructose), and Eldridge's coach thought that by eating honey before he ran, Eldridge would have more energy. But the coach was wrong for two reasons, as we will see. Let's reconsider how sugar is used in the body, and the differences between starch and sugar.

Carbohydrates are digested by breaking down large molecules to smaller molecules, the final product of the digestion being monosaccharides. Starch is hydrolyzed to glucose; disaccharides are hydrolyzed to glucose and other monosaccharides. The monosaccharides are absorbed into the body, where glucose is used for energy and the others are converted to glucose. Protein and fat are not used for energy until the available glucose is consumed.

In Section 13 we discussed the relation that has been hypothesized between sugar and atherosclerosis. Recall that sugar may be digested and absorbed into the body more rapidly than it is used by the body for energy. In this event, excess glucose is converted to glycogen and stored in the liver. When the capacity of the liver to store glycogen is reached, glucose is converted to fat, most of which is stored for future use. However, if the theory discussed in the previous section is correct, the fat concentration in the blood increases during this conversion, and the increased fat level appears to hasten the development of atherosclerosis.

To get back to Eldridge, if he had eaten a normal meal a few hours before the race, he would have had plenty of glucose available to his body for racing so the honey was unnecessary. Thus the coach was wrong on one count. He was also wrong for not considering the role of a hormone from the pancreas, called insulin.

To understand what insulin had to do with Eldridge's collapse, we need to introduce a new term. Eldridge collapsed because he was suffering from a condition called hypoglycemia. The suffix "-emia" means "related to the blood" and the syllable "-glyc-" means "sweet" or "related to sugar." The prefix "hypo-" means "too little." Hypoglycemia is the condition of low blood sugar.

The apparent paradox of glucose causing low blood sugar is explained by the role of insulin. The function of insulin is to help the body use glucose, and keep the level of glucose in the blood from getting too high. If blood sugar rises, as after eating, insulin is released into the blood, causing the amount of sugar in the blood to decrease.

While insulin helps to keep the blood glucose level from becoming too high, other chemicals help to keep the glucose level from getting too low. One is an enzyme, called insulinase, that destroys insulin. Another is the hormone glucagon. When the glucose level becomes too low, glucagon stimulates the breakdown in the liver of glycogen into glucose. The liver then releases this glucose into the blood, so the blood glucose level rises. Thus the body has mechanisms for keeping the amount of glucose in the blood within the proper range.

In Eldridge's case, eating the honey resulted in a rapid rise in blood sugar which in turn triggered the release of a large amount of insulin into his blood. Because Eldridge was exercising, his body used up the sugar rapidly--so rapidly that insulin could not be destroyed quickly enough. Glucose continued to be used at an abnormally high rate even after the race.

The result was an imbalance: the sugar level had already dropped but the large amount of insulin in Eldridge's blood was still signaling his body to remove even more sugar from his blood. The concentration of sugar in Eldridge's blood decreased to a subnormal level. The second flaw in the coach's theory was that the high glucose level in the blood upset the glucose-insulin balance.

As can be seen from Eldridge's example, the body's mechanisms for regulating blood sugar level are not capable of responding quickly enough to a rapidly changing concentration of blood sugar. This suggests another reason (aside from the possible link between sugar and artherosclerosis) why it is better to consume starch than sugar. When starch is digested, glucose is released more slowly and at a more uniform rate into the blood. This means that the amount of insulin released into the blood is also more moderate and an imbalance such as that of Eldridge's case is not likely.

Blood sugar level becomes lowest one to three hours after the intake of sugar. Not enough sugar is available for the needs of the body, and the body becomes weak. When the concentration of sugar in the blood falls to less than two-thirds of normal, hypoglycemia occurs. Although hypoglycemia is rarely serious, the symptoms (sweating, shaking, fatigue and hunger) can be alarming. Mild episodes are common; you may recall experiencing one yourself.

There is no evidence to support taking sugar before an athletic event, although it may not hurt an athlete's performance. Athletic performance should be improved by a good diet and physical conditioning.

Taking honey before an athletic event is not the most common cause of hypoglycemia. Millions of Americans upset their blood sugar level by a breakfast of sweet rolls and several cups of coffee, each with a few spoonfuls of sugar. Too much carbohydrate, especially sugar, is taken on an empty stomach. This breakfast may help to start the day, but it also causes the letdown that comes at 11 o'clock. This late-morning weakness and hunger has the same physiological cause as Eldridge's collapse after the race.

We have been discussing hypoglycemia that occurs to normal people as a result of too much sugar being absorbed into the body in a short period of time. However, it is worth mentioning that a few people may suffer from repeated episodes of hypoglycemia without consuming unusual quantities of sugar. The reasons for chronic low blood sugar are not known, but there is some indication that the cause may have to do with insufficient secretion of glucagon.

In our study of nutrition we will have other occasions to consider dietary requirements. In this instance and in other situations to be considered, we will see that obtaining the dietary requirements is not all there is to good nutrition--how you distribute the foods which supply these requirements among your daily meals is also important. For example, the fact that you eat one sweet roll and drink a cup of coffee during the day does not necessarily mean that you do not have a good diet, but this combination for breakfast is not a good idea.

14-3 Homeostasis and Feedback

What do homeostasis and feedback have to do with the blood sugar level?

The case of Eldridge and his problems with hypoglycemia illustrates an important property of all life--that life exists within a narrow range of conditions and that we have built-in mechanisms to maintain these conditions. When the blood-sugar level is too high, insulin is released causing glucose to be removed from the blood. When the blood glucose level is too low, the pancreas secretes a different hormone, glucagon, causing glycogen to break down to glucose thus compensating for the low blood sugar.

Body regulation of this type is known as homeostasis (from "homeo" meaning "same" and "stasis" meaning "standing"). Homeostasis is the property of resisting change in an organism. It is one of the most fundamental properties of life and is expressed not only in maintenance of a fairly constant blood-sugar level, but in many other essential ways. For example, there are homeostatic mechanisms to regulate the fluid volume of our blood, so drinking a liter of water will not dilute our blood significantly. In addition, our blood pH is maintained by an elegant regulatory system that we referred to in Unit I. Basically, through control of the concentration of HCO_3^- and CO_2 in the blood, we are able to maintain a rather constant pH in our blood.

Whenever there is homeostasis, there must also be signals that direct the body to respond to any significant deviation from the normal range. There must be signals that control the production of insulin and glucagon, and there must be signals that cause the body to act in a way to increase or decrease the pH of the blood as needed. These signals are called feedbacks.

Negative feedback is a situation in which a change (for example, an increase in blood glucose) causes events (the release of insulin) that oppose the change (decreasing blood glucose). Negative feedback is important in biology, because it maintains homeostasis. The secretion of glucagon in response to low blood glucose is another example of negative feedback. A decrease in blood glucose causes the secretion of glucagon, which opposes the decrease by causing glycogen to be converted to glucose and released to the blood.

On the other hand, positive feedback is a situation in which an excess of something (heat, blood sugar concentration, etc.) triggers production of still more of that thing, or a deficiency leads to a further decrease. One biological example of positive feedback involves the conversion of pepsinogen to pepsin in the stomach. HCl is required to start the conversion, but pepsin acts as a catalyst for its own formation. Therefore, once some pepsin forms, it causes the formation of more pepsin. In other words, an increase in the amount of pepsin leads to a further increase. This process, fortunately, cannot go on indefinitely and is limited by the amount of pepsinogen being secreted into the stomach.

However, positive feedback leads to instability and is uncommon in the body. Negative feedback, which leads to homeostasis is far more common.

What were two flaws in Coach Jones' theory about honey?

What is meant by positive and negative feedback? How is insulin involved in a feedback mechanism?

What was Eldridge's problem? How was his problem related to homeostasis?

What other factors are important in eating habits besides the amounts of nutrients in the foods?

Vocabulary:

homeostasis (HO-mee-o-STAY-sis)--the property of resisting change in the body.

hypoglycemia (HY-po-gly-SEE-mee-uh)--a condition in which the level of blood sugar is below normal.

insulin (IN-suh-lin)--a pancreatic hormone that helps to control the blood-sugar level.

negative feedback--a situation in which a change causes an opposition to that change.

positive feedback--a situation in which a change causes a further change in the same direction.

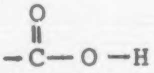
SECTION 15: FATS

15-1 Organic Acids

What is the functional group in organic acids?

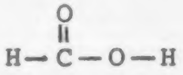
The hydrolysis of both fats and proteins that occurs during digestion produces substances known as organic acids. In Unit I acids were defined as substances that produce H^+ ions in solution. Organic acids produce H^+ ions, but the have other structural characteristics as well.

Organic acids have a characteristic functional group called the carboxyl group, which is often written as -COOH.



$$-\overset{\overset{\displaystyle O}{\|}}{C}-O-H$$

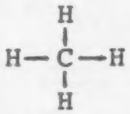
The simplest organic acid is formic acid, HCOOH.



$$H-\overset{\overset{\displaystyle O}{\|}}{C}-O-H$$

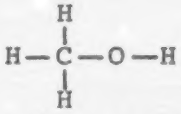
FORMIC ACID

Formic acid could also be called methanoic acid, since it contains one carbon atom, just as methane and methyl alcohol do.



$$H-\underset{\underset{\displaystyle H}{|}}{\overset{\overset{\displaystyle H}{|}}{C}}-H$$

METHANE

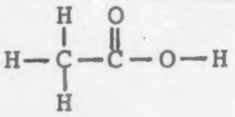


$$H-\underset{\underset{\displaystyle H}{|}}{\overset{\overset{\displaystyle H}{|}}{C}}-O-H$$

METHYL ALCOHOL

However, it has kept its original name, which is from the Latin word for ants, where it was first found long before its relation to other substances was known.

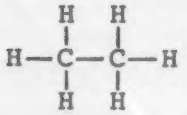
A second organic acid is acetic acid, which contains two carbon atoms.



$$H-\underset{\underset{\displaystyle H}{|}}{\overset{\overset{\displaystyle H}{|}}{C}}-\overset{\overset{\displaystyle O}{\|}}{C}-O-H \quad \text{or } CH_3COOH$$

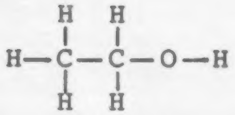
ACETIC ACID

Acetic acid is the ingredient which gives vinegar its characteristic taste and smell. The name acetic acid also predates the time when the standard system of names was adopted. Since acetic acid has two carbons, like ethane and ethyl alcohol, its systematic name would be ethanoic acid.



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

ETHANE

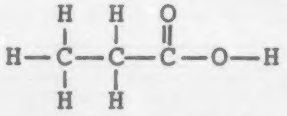


$$\begin{array}{ccccccccc} & & H & & H & & & & \\ & & | & & | & & & & \\ H & - & C & - & C & - & O & - & H \\ & & | & & | & & & & \\ & & H & & H & & & & \end{array}$$

ETHYL ALCOHOL

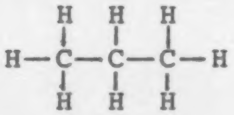
You have used acetic acid in the laboratory.

The acid with a chain of three carbon atoms is called propanoic acid. Its name indicates that it has the same number of carbon atoms as propane. The molecular formula of propanoic acid may be written either CH_3CH_2COOH or C_2H_5COOH.



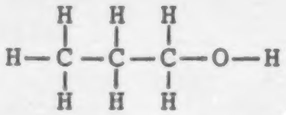
$$\begin{array}{ccccccccccc} & & H & & H & & O & & & & \\ & & | & & | & & \| & & & & \\ H & - & C & - & C & - & C & - & O & - & H \\ & & | & & | & & & & & & \\ & & H & & H & & & & & & \end{array}$$

PROPANOIC ACID



$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & \\ & & H & & H & & H & & \end{array}$$

PROPANE



$$\begin{array}{ccccccccccc} & & H & & H & & H & & & & \\ & & | & & | & & | & & & & \\ H & - & C & - & C & - & C & - & O & - & H \\ & & | & & | & & | & & & & \\ & & H & & H & & H & & & & \end{array}$$

NORMAL-PROPYL ALCOHOL

Propanoic acid is added to bread to inhibit the growth of mold, and to foot powders to inhibit the growth of fungi.

Organic acids have typical chemical reactions, and often chemists wish to write an equation which is true for any acid. This is done by using the symbol R to represent the part of the molecule other than the functional group. Thus R-COOH indicates an entire class of organic acids, and could be H-COOH, CH_3-COOH, CH_3CH_2-COOH or some other organic acid. For example, organic acids produce H^+ ions by the reaction

$$RCOOH \rightarrow H^+ + RCOO^-$$

R may stand for H, in which case the equation represents the production of H^+ ions by formic acid.

$$HCOOH \rightarrow H^+ + HCOO^-$$

If R stands for CH_3, the equation indicates the dissociation of acetic acid.

$$CH_3COOH \rightarrow H^+ + CH_3COO^-$$

R may be used in the same way with other functional groups. ROH is a general formula for alcohols with one hydroxyl group, and can symbolize CH_3OH, CH_3CH_2OH, $CH_3CH_2CH_2OH$, etc. Remember that R is a shorthand notation and not the symbol of an element.

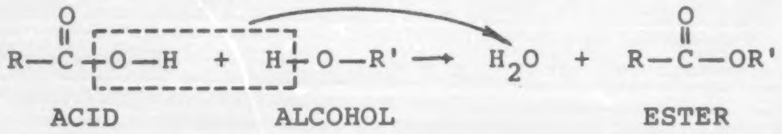
15-2 Esters

What happens when an alcohol reacts with an organic acid?

What do the products taste like?

When organic compounds react, usually the functional group is the part of the molecule that participates in the reaction. An example is the reaction between an alcohol and an organic acid. The hydroxyl group of the alcohol reacts with a hydrogen from the carboxyl group of the acid; the remainders of the molecules do not change.

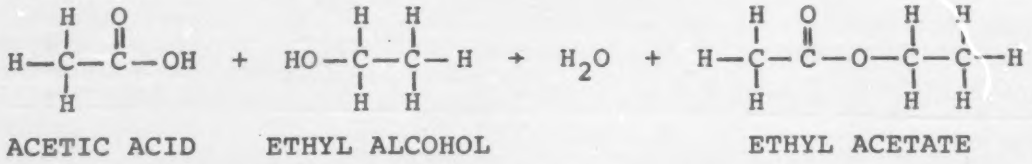
When an alcohol and an organic acid react, the acid loses a hydrogen atom and an oxygen atom, and the alcohol loses a hydrogen atom. These three atoms combine to form water. The remaining atoms of the acid and the alcohol join to form a type of compound called an ester. The elimination of water when substances react is the opposite of hydrolysis and is called dehydration. The term "synthesis" is used by organic chemists to mean "production of a larger molecule from simpler molecules." So the production of an ester from an acid and an alcohol is called dehydration synthesis.



$$R-\overset{O}{\overset{\|}{C}}-O-H + H-O-R' \longrightarrow H_2O + R-\overset{O}{\overset{\|}{C}}-OR'$$

Observe the symbols R and R'. The use of R indicates that this reaction is typical of organic acids in general, and R' indicates that this reaction is typical of alcohols. The prime (') of the symbol R' indicates that the carbon chain it represents may be different from the chain represented by R. The formula RCOOR' is characteristic of all esters and may be used as a general formula.

The reaction to form an ester is characteristic of all organic acids and all alcohols. For example, ethyl alcohol and acetic acid combine to form the ester named ethyl acetate.



$$H-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-OH + HO-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H \rightarrow H_2O + H-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-O-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$$

We introduce esters because fats are esters, although they are formed from more complex alcohol and acid molecules than the simple ones we have used as examples. But the simpler esters, such as ethyl acetate, are not without interest in the study of nutrition. Many alcohols are toxic, and acids tend to have unpleasant odors and tastes, but the esters formed when these same two types of compound react generally have pleasant odors and tastes. The tastes and aromas of many fruits are mainly due to esters. Ethyl acetate helps give pineapples their characteristic aroma and taste. Other esters have the aromas of bananas, wintergreen, apples, pears, etc.

15-3 Chemistry of Fats

What is the structure of a fat molecule?

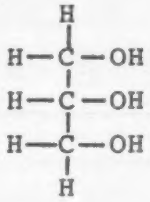
What substances are formed during the digestion of fats?

Living cells contain certain esters that are generally insoluble in water but soluble in many organic solvents. These esters are called lipids. Lipids are found in many parts of our bodies--in cell membranes and as protective waxes and oils of the skin and ears.

One class of lipids is known as fats. This is a class of nutrients we have been referring to in digestion. While a gram of carbohydrate provides approximately four calories of energy, a gram of fat provides about nine calories, so fats are important as a source of energy. The body stores fats as a reserve source of chemical energy. Stored fat is also used by the body for insulation, and for padding organs such as the kidneys.

Monosaccharides and disaccharides have similar molecular structures; the group of substances known as fats also have chemical similarities.

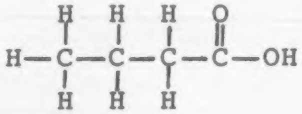
Fats are esters formed from an alcohol called glycerol and a class of organic acids called fatty acids. Glycerol has three hydroxyl groups; its structural formula is



$$\begin{array}{ccccc} & & \mathrm{H} & & \\ & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{OH} \\ & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{OH} \\ & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{OH} \\ & & | & & \\ & & \mathrm{H} & & \end{array}$$

GLYCEROL

Fatty acids have one carboxyl group and from four to 24 carbon atoms, generally an even number, in a chain with no branching. The simplest fatty acid is butanoic acid ($CH_3CH_2CH_2COOH$), which occurs in milk and milk products such as butter.

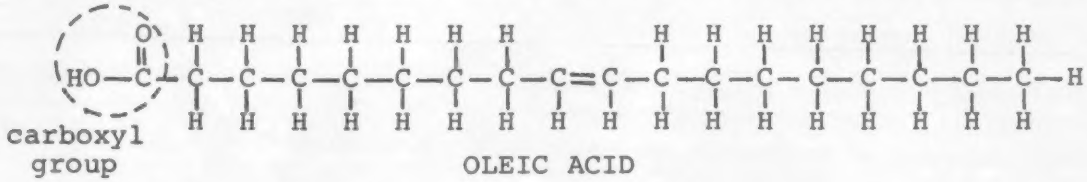


$$\begin{array}{ccccccccccc} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{O} & & \\ & & | & & | & & | & & \| & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{OH} \\ & & | & & | & & | & & & & \\ & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & & & \end{array}$$

BUTANOIC ACID

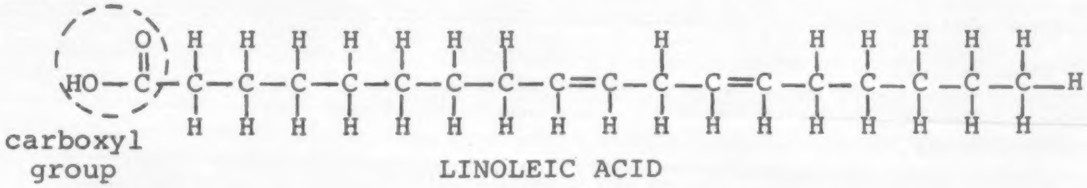
The molecules of the most common fatty acids, however, have longer chains of carbon atoms. The fatty acids obtained from foods typically have 16 or 18 carbons per molecule.

A characteristic that distinguishes some fatty acids from others, and is of great importance in nutrition, is their degree of saturation. Butanoic acid has no double or triple bonds between carbon atoms and is therefore a saturated fatty acid. Many fatty acids have one or more double bonds. Oleic acid, which is obtained from vegetable oils and is shown below, is a monounsaturated, or singly unsaturated, fatty acid--it has one double bond between carbon atoms.

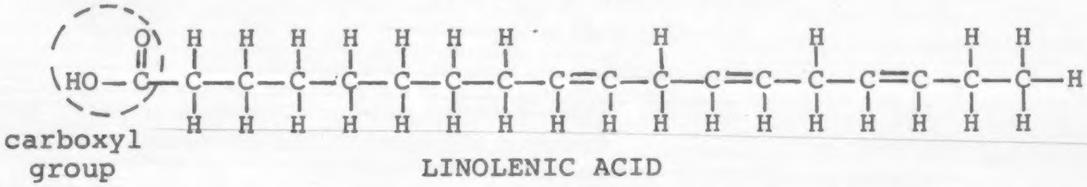


OLEIC ACID

Linoleic acid and linolenic acid, which also occur in vegetable oils and are shown below, are both polyunsaturated fatty acids. Linoleic acid has two and linolenic acid three double bonds between carbon atoms.

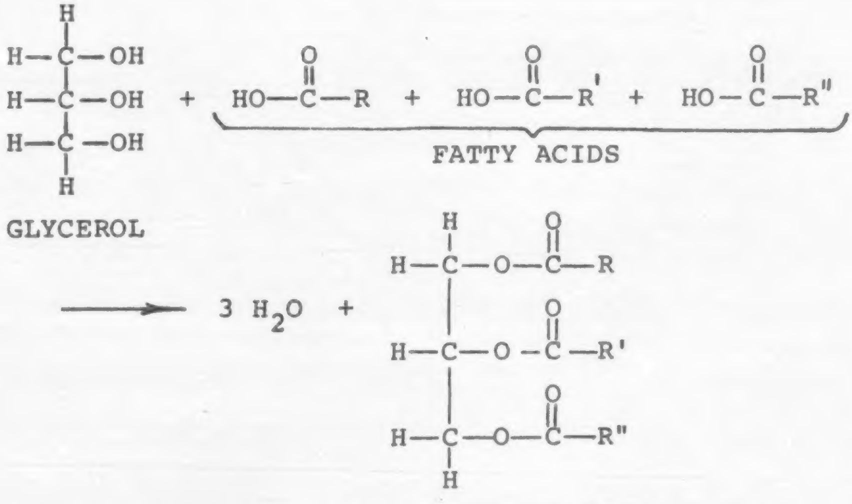


LINOLEIC ACID



LINOLENIC ACID

Alcohols react with acids to form esters by dehydration synthesis. Since glycerol has three hydroxyl groups, it can react with three fatty acids.

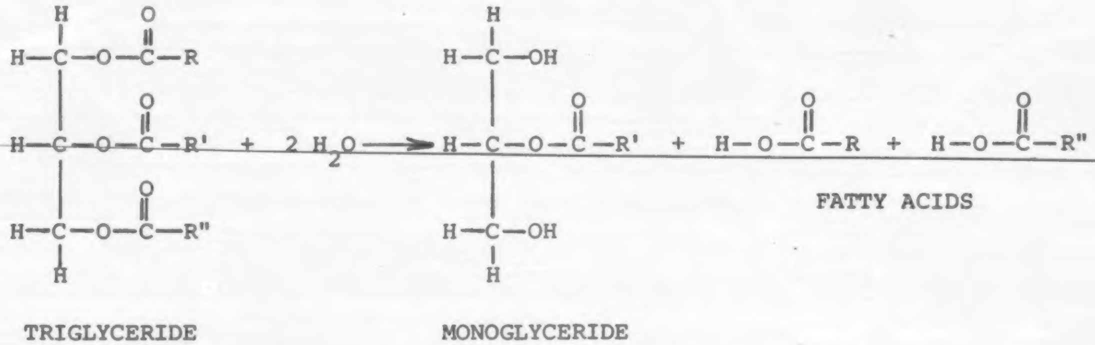


FAT (TRIGLYCERIDE)

The product of this reaction has three ester groups. It is called a triglyceride. Triglycerides are fats. The three fatty acids may be the same, or they may be different. One, two or three of them may be saturated, with the remainder being unsaturated.

We saw that a disaccharide, in the presence of the appropriate enzyme, hydrolyzes to produce two monosaccharides. A triglyceride (fat) also hydrolyzes under certain conditions.

You may recall from our discussion of digestion that lipases break certain bonds in fats. This is an example of enzymatic hydrolysis. During digestion, two parts of a triglyceride molecule split off by hydrolysis to form fatty acids. The remainder of the triglyceride becomes an ester of glycerol and one fatty acid; the compound is called a monoglyceride.



The symbols R, R' and R" have again beeen used to indicate that three different fatty acids may be involved. Observe also that hydrolysis is the reverse process of dehydration synthesis. Fatty acids react with glycerol to form fats by dehydration synthesis, while fatty acids break off from fats by hydrolysis.

This hydrolysis reaction occurs during the digestion of fats. The fatty acids and monoglycerides produced during digestion are able to pass through the walls of the intestines and enter the body. Interestingly enough, as soon as the fatty acids and monoglycerides are absorbed, they are converted back to fats and transported through the body in that form. Most of the fat is carried by the lymphatic system, but some travels in the blood. This fat may be deposited as fat tissue, or may cause problems that will be discussed in the next section.

What types of substances react to form esters?

What types of substances react to form fats?

Are esters and fats formed by hydrolysis or dehydration synthesis?

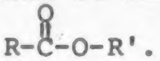
Are fats digested by hydrolysis or dehydration synthesis?

Vocabulary:

carboxyl group (car-BOX-ill)--the functional group $-\overset{O}{\overset{\|}{C}}-OH$, possessed by all organic acids.

dehydration--loss of water.

dehydration synthesis--the formation of a molecule from smaller molecules involving the elimination of a water molecule.

ester--a compound formed by the dehydration synthesis reaction of an alcohol and an organic acid, with the general formula  $R-\overset{O}{\overset{\|}{C}}-O-R'$.

fat--a lipid formed from glycerol and three fatty acids; a triglyceride.

fatty acid--an organic acid having one carboxyl group and between four and twenty-four carbon atoms in an unbranched chain.

monounsaturated--having one double (or triple) bond between carbon atoms.

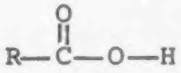
organic acid--a compound containing a carboxyl group.

polyunsaturated--having more than one double (or triple) bond between carbon atoms.

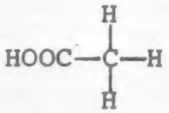
PROBLEM SET 15:

1. Which of the following is an organic acid?

a. CH_3-OH

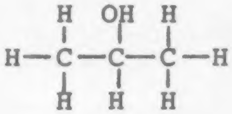
b.  $R-\overset{O}{\overset{\|}{C}}-O-H$

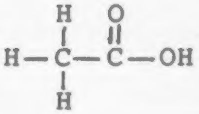
c. HCl

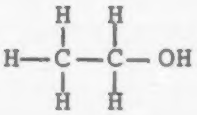
d. 

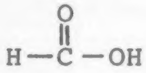
2. Write the general formula for an organic acid and circle the functional group.

3. Which of the following compounds are alcohols and which are organic acids?

a. 

b. 

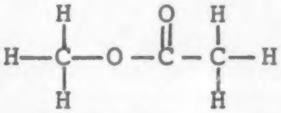
c. 

d.  $H-\overset{O}{\overset{\|}{C}}-OH$

e. R—OH

(R contains carbons and hydrogens only)

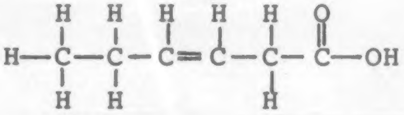
4. Write the structural formulas of the acid and alcohol which reacted to give the ester shown below.



$H_3C-O-C(=O)-CH_3$

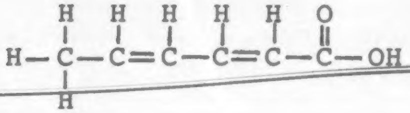
5. Identify each of the following fatty acids as saturated, monounsaturated or polyunsaturated.

a.



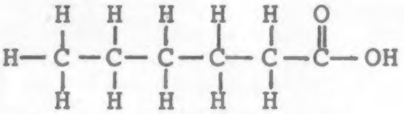
$CH_3-CH_2-CH=CH-CH_2-COOH$

b.



$CH_3-CH=CH-CH=CH-COOH$

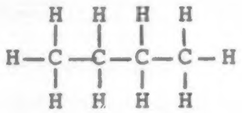
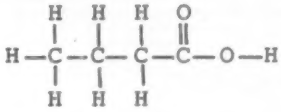
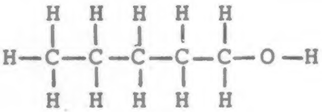
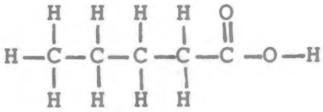
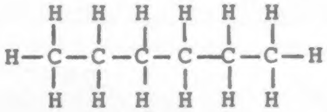
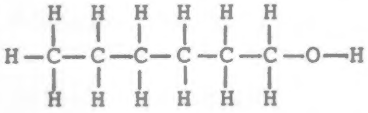
c.



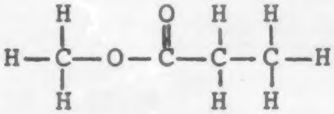
$CH_3-CH_2-CH_2-CH_2-CH_2-COOH$

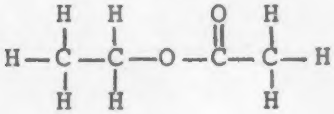
Write the structural formula of a fat formed by glycerol and these three fatty acids.

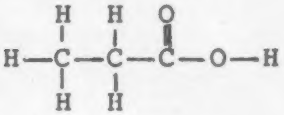
6. Some information is missing in the following table, at places indicated by letters (a, b, c, etc.). Supply the missing names and formulas.

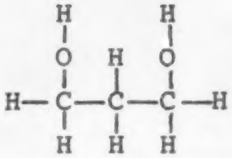
HYDROCARBON	ALCOHOL	ORGANIC ACID
 $CH_3-CH_2-CH_2-CH_3$ NORMAL-BUTANE	(a) NORMAL-BUTYL ALCOHOL	 $CH_3-CH_2-CH_2-C(=O)-O-H$ NORMAL-BUTANOIC ACID
(b) NORMAL-PENTANE	 $CH_3-CH_2-CH_2-CH_2-CH_2-O-H$ NORMAL-PENTYL ALCOHOL	 $CH_3-CH_2-CH_2-CH_2-C(=O)-O-H$ (c)
 $CH_3-CH_2-CH_2-CH_2-CH_2-CH_3$ NORMAL-HEXANE	 $CH_3-CH_2-CH_2-CH_2-CH_2-CH_2-O-H$ (d)	(e) NORMAL-HEXANOIC ACID

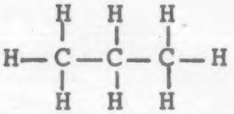
7. Indicate whether each of the following compounds is a hydrocarbon, alcohol, ester or acid.

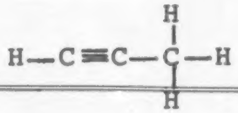
a. 
$CH_3OCOCH_2CH_3$

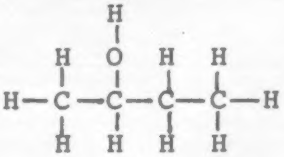
e. 
$CH_3CH_2OCOCH_3$

b. 
CH_3CH_2COOH

f. 
$HOCH_2CH_2CH_2OH$

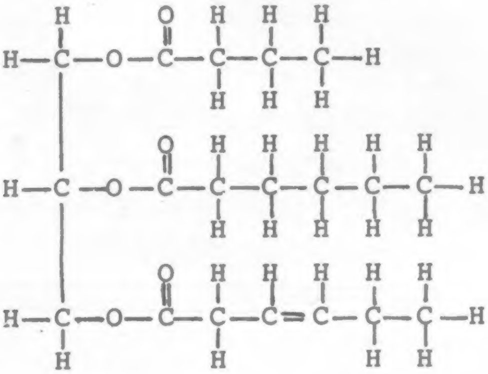
c. 
$CH_3CH_2CH_3$

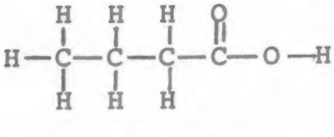
g. 
$HC\equiv CCH_3$

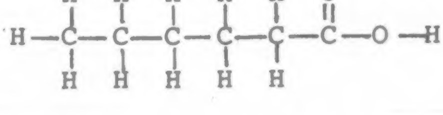
d. 
$CH_3CH(OH)CH_2CH_3$

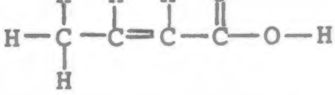
8. What two compounds or types of compounds are formed by the hydrolysis of fats?

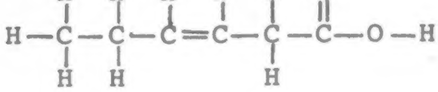
9. Which of the fatty acids listed below are obtained by hydrolysis of the fat with the following structural formula?

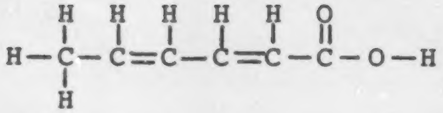

$$\begin{array}{l} CH_2OCOCH_2CH_2CH_3 \\ CHOCOCH_2CH_2CH_2CH_2CH_3 \\ CH_2OCOCH_2CH=CHCH_2CH_3 \end{array}$$

a. 
$CH_3CH_2CH_2COOH$

c. 
$CH_3CH_2CH_2CH_2CH_2COOH$

b. 
$CH_3CH=CHCOOH$

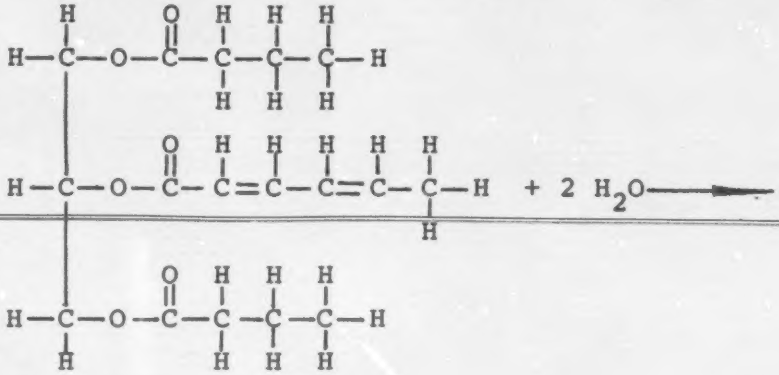
d. 
$CH_3CH_2CH=CHCH_2COOH$

e. 

$H-\underset{H}{\overset{H}{C}}-\overset{H}{C}=\overset{H}{C}-\overset{H}{C}=\overset{H}{C}-\overset{O}{\overset{\|}{C}}-O-H$

Which of the compounds above are saturated, which are monounsaturated and which are polyunsaturated?

10. Complete the following equation for the hydrolysis of a fat.



SECTION 16: FATS IN THE DIET

16-1 Fats and Health

Are saturated fatty acids or unsaturated fatty acids preferable in a diet?

Why is the type of fat in a diet important?

Fats are valuable sources of energy and have other functions in our bodies as well. However, not all fats are equally beneficial.

In the previous section we distinguished between saturated fatty acids and unsaturated fatty acids. Saturated fatty acids have no double bonds between carbons, monounsaturated fatty acids have one double bond between carbons and polyunsaturated fatty acids have more than one.

Fat occurs in foods as a mixture of many fat compounds, which in turn are composed of a variety of fatty acids. Fats with a large proportion of unsaturated fatty acids generally have lower melting points than fats with a large proportion of saturated fatty acids.

Fats that are liquid at room temperature are called oils. Most oils used as foods are obtained from vegetables and are not to be confused with motor oils. Motor oils are derived from petroleum and are not fats, but hydrocarbons. Most food oils (coconut oil is an exception) contain a large percentage of unsaturated fatty acids. Fats of animal origin are composed largely of saturated fatty acids.

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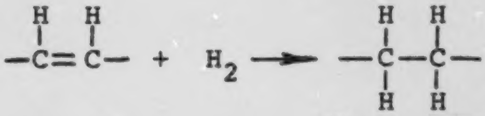
The following table gives the percentages of fatty acids that are saturated, monounsaturated and polyunsaturated in the fats in a few foods.

	Fat Source	Per Cent Saturated	Per Cent Monounsaturated	Per Cent Polyunsaturated
animal	Beef	53.5	44.0	3.0
	Eggs	35.0	50.0	15.0
	Butter	65.0	31.5	3.5
vegetable	Corn Oil	15.5	29.0	55.5
	Olive Oil	15.5	75.0	9.5
	Safflower Oil	7.0	18.5	74.0

Margarine, incidentally, is made from vegetable oils, such as corn oil, by the process of hydrogenation. Hydrogen reacts with the carbons that are next to double bonds in unsaturated fatty acids.



$$-\overset{H}{\overset{|}{C}}=\overset{H}{\overset{|}{C}}- \;+\; H_2 \longrightarrow -\underset{\underset{H}{|}}{\overset{H}{\overset{|}{C}}}-\underset{\underset{H}{|}}{\overset{H}{\overset{|}{C}}}-$$

The fatty acids produced are thus more highly saturated than the original fatty acids, and the resulting fat has a higher melting point. Margarines differ widely in their proportion of saturated fatty acids, depending upon the degree of hydrogenation. Some margarines even contain a greater percentage of saturated fatty acids than butter. As a general rule of thumb, the softer the margarine at room temperature, the lower the proportion of saturated fatty acids.

We have gone to some trouble to distinguish unsaturated fatty acids from saturated fatty acids. What difference does it make? The difference has to do with atherosclerosis and with cholesterol. Cholesterol is an alcohol with a large molecular weight and a complex structure. It can react with a fatty acid to form an ester. Cholesterol is synthesized in our livers, and additional cholesterol is obtained from food sources--notably egg yolks, meat, butter and some seafood. It has a variety of functions, is stored in our livers and is found in other parts of our bodies.

According to the Framingham Study (Section 2-2), a high concentration of cholesterol in a person's blood is associated with coronary heart disease. This is a statistical correlation, and, as we have discussed, such correlations are not absolute proof. In this case, there is also other evidence relating cholesterol to atherosclerosis.

Atherosclerosis is the condition in which lipids, including fats, deposit in the walls of large blood vessels, and cholesterol is one of the main components of these deposits. The rate at which atherosclerotic deposits form appears to be related to the concentration of cholesterol in the blood. The accumulation of deposits in the walls of blood vessels gradually closes off the vessels to the flow of blood. Atherosclerosis is the leading cause of heart attacks.

The body may obtain cholesterol directly from foods, and it may synthesize it from fatty acids, amino acids, glucose or ethyl alcohol. It appears that most people synthesize more cholesterol when less is included in their diets, so that the concentration of cholesterol in the blood is not necessarily related to the amount in the diet. However, some people apparently have high cholesterol levels because the liver does not decrease production to compensate for the cholesterol supplied by the diet. Also, a diet may supply more cholesterol than the liver would produce if cholesterol were absent from the diet. When this occurs, the diet is responsible for a high blood cholesterol level.

But the diet is more commonly related to cholesterol in the blood in another way, because the type of fatty acid in the diet affects cholesterol concentration. Polyunsaturated fatty acids tend to decrease cholesterol concentration, while monounsaturated fatty acids appear to have no effect. But saturated fatty acids increase cholesterol levels. Current evidence indicates that the total intake of saturated fatty acids is the most important dietary factor affecting the blood cholesterol level.

Certain people with high cholesterol levels have been put on diets low in saturated fatty acids and high in polyunsaturated fatty acids. After several months on this diet, their cholesterol concentrations have been found to decrease significantly. This is part of the evidence in favor of polyunsaturated fatty acids.

For this reason it is desirable that fat rich in polyunsaturated fatty acids be used in a diet. Oils are a desirable source of fat. Fat in meat, eggs and other food from animals is higher in saturated fatty acids. Therefore, these foods constitute a less desirable source of fat.

Eliminating sources of saturated fatty acids and cholesterol from our diets would be difficult, because many of these foods are also good sources of protein and include such favorites as beef, eggs and cheese. A common recommendation is that the ratio of polyunsaturated fatty acids to saturated fatty acids be at least one to one (1:1) for most people, and at least two to one (2:1) for people with high blood cholesterol levels.

A few ways to reduce the saturated fatty acids in your diet are to drink low-fat or non-fat milk, use soft margarine instead of butter and use oils that are high in polyunsaturated fatty acids. (Note safflower oil in the table given earlier in this section.)

Complete elimination of fat from the diet is also undesirable because we need specific fatty acids for certain functions but cannot synthesize them in our bodies. Linoleic acid (its structure was given as an example of an unsaturated fatty acid in Section 15) is one such fatty acid. Since linoleic acid must be supplied by the diet, it is said to be an essential fatty acid. Arachidonic acid, which has twenty carbons and four double bonds, is also needed by the body and either must be obtained from the diet directly or synthesized within the body from linoleic acid. Laboratory animals placed on diets completely lacking in the essential fatty acids have eventually developed liver damage and skin sores. Retarded growth and abnormal pregnancies have also been traced to diets lacking the essential fatty acids.

What kind of fats tend to be solids at room temperature? What kind tend to be liquids?

What is the relation between the saturation of fatty acids in the diet and the amount of cholesterol in the blood?

Is the amount of cholesterol in the blood determined by the amount of cholesterol in the diet?

What is the relation between cholesterol and atherosclerosis?

Why are polyunsaturated fatty acids preferable to saturated fatty acids?

Vocabulary:

essential fatty acid--fatty acid that must be supplied by the diet.

hydrogenation (hy-DRAH-juh-NAY-shun)--reaction with hydrogen; specifically, the reaction of hydrogen with carbons on either side of a double bond.

oil--a fat that is a liquid at room temperature.

SECTION 17: PROTEINS

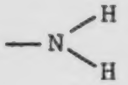
17-1 Amines and Amino Acids

What functional groups are found in amino acids?

The alcohols, organic acids and esters we have discussed as well as carbohydrates and fats, contain only carbon, hydrogen and oxygen. But many other organic compounds, including amino acids, contain nitrogen. Recall that when proteins are digested, they are broken down to amino acids.

Amino acids contain two functional groups. One should be no stranger to you; it is the carboxyl group, -COOH, which is characteristic of all organic acids. The other functional group in amino acids is called the amino group, and contains a nitrogen atom. (The word "amino" suggests a relation to ammonia, NH_3.)

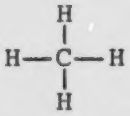
A nitrogen atom may fill its outer shell by sharing electrons with three other atoms, so nitrogen typically forms three covalent bonds. In an amino group, two of these bonds are to hydrogen atoms and the third is to an atom in the rest of the molecule. Thus the amino group may be represented as

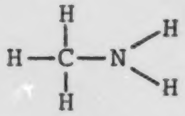

or $-NH_2$

(The diagonal arrangement of bonds in the structural formula is only a matter of style, and is not meant to indicate shape.)

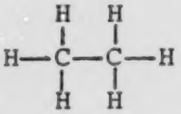
The simplest compounds that contain an amino group are primary amines, in which the amino group is joined to a hydrogen fragment.

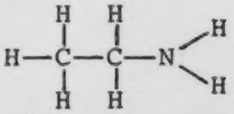
The substance with the following structural formula is called methylamine (CH_3NH_2). Methane is shown for comparison.


METHANE


METHYLAMINE

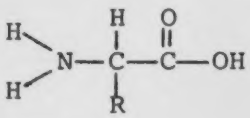
The compound in which one hydrogen atom in ethane is replaced by an amino group is ethylamine ($CH_3CH_2NH_2$).


ETHANE

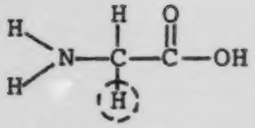

ETHYLAMINE

The general formula for primary amines is $R\text{-}NH_2$. The system for naming primary amines, as you can see from the examples of methylamine and ethylamine, is similar to the system for naming other classes of organic compounds, such as alcohols.

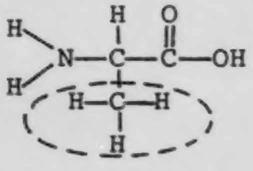
Amino acids, as we stated, contain both an amino group and a carboxyl group. The general formula for all amino acids is



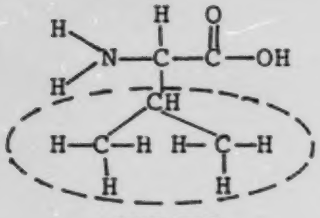
The part of the molecule represented by R differs from one amino acid to another. The formulas of a few amino acids are shown on the following page. (Groups represented by "R" in the general formula are circled.)



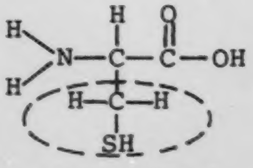
GLYCINE



ALANINE



VALINE



CYSTEINE

The first amino acid was discovered by chance. In 1820, the French chemist Braconnot was heating a protein called gelatin with acid. After the water had evaporated, he found crystals of a sweet-tasting substance. He named these crystals "sugar of gelatin," but they later came to be called glycine. "Glyc" as in glycine, glycogen and hypoglycemia comes from the Greek word for "sweet." Chemists later discovered that glycine had an amino group and a carboxyl group attached to the same carbon atom. Soon other substances were found with amino and carboxyl groups attached to the same carbon, and eventually the list of amino acids that occur in biological systems grew to over 20. From these amino acids, all the proteins in plants and animals are constructed.

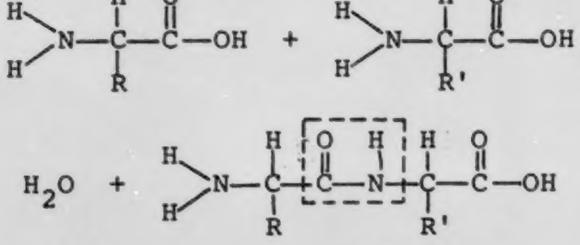
17-2 The Chemistry of Proteins

How do amino acids join together to form proteins?

How are amino acids formed during digestion of proteins?

Proteins are important structural components of living cells. Many structures of the body, such as muscles, hair and skin, are composed mainly of protein. Proteins also serve specialized functions in the body as hormones, antibodies and enzymes.

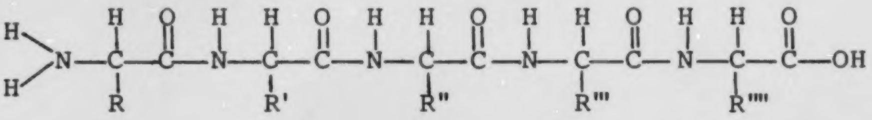
Proteins are formed from amino acids by dehydration synthesis. Two amino acids form a bond when the amino group of one molecule reacts with the carboxyl group of the other molecule. As in all dehydration synthesis reactions, water is formed.



PEPTIDE

The product of this reaction is a peptide, more specifically a dipeptide. The -C=O and -N-H groups joining the two amino acids are called a peptide linkage.

The dipeptide thus created is free to react with another amino acid by forming another peptide bond. The process may continue until a very large molecule has been built. "Poly" means "many," so this is a polypeptide.

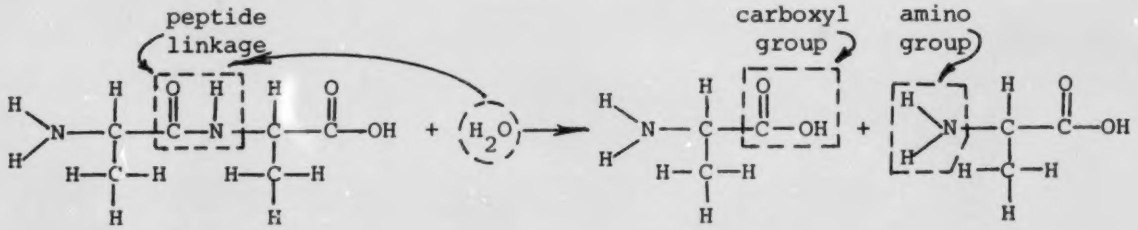


Proteins are extremely large, complex polypeptides. A typical protein consists of between several hundred and several thousand amino acids. The molecular weights of proteins vary from 5,000 to 10,000,000 amu. (Just hope your teacher does not require you to calculate the molecular weight of a protein from its formula!)

Each protein has a definite arrangement of amino acids. Pepsin, for example, has a different arrangement of amino acids from amylase, and both of these proteins are distinct from insulin.

The relationship of amino acids to proteins may be likened to the relationship of letters to words. A word has a definite arrangement of letters. If one letter is changed or is missing, the word may take on an entirely different meaning, or have no meaning. If a protein lacks one of its amino acids, it may be unable to serve the specific function required of it by the body.

Proteins may be broken down to smaller units in the same way that carbohydrates and fats are, by hydrolysis. This is what happens in the digestion of proteins. In fact, the reactions catalyzed by pepsin and other proteinases during digestion are hydrolyses. Under the proper conditions, water will react with a peptide linkage. The following equation represents the hydrolysis of the dipeptide alanylserine to form the amino acids alanine and serine.



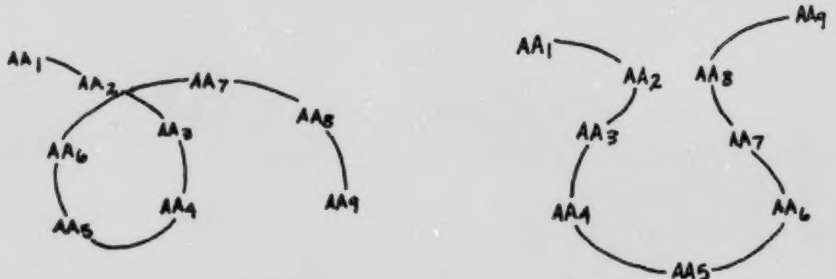
ALANYLSERINE ALANINE SERINE

17-3 The Architecture of Proteins

How is the three-dimensional structure of a protein related to its activity?

You may recall that in our discussion of enzymes and substrates (Section 4), we emphasized the structural fit between the two. This is a three-dimensional fit--it has been likened to a lock and key. The shape of a protein is crucial to the interaction between an enzyme and a substrate.

The structure of a protein involves more than simply the sequence of amino acids in the chain, because a polypeptide chain can twist in many different ways as suggested schematically in Figure 1. ("AA" stands for "amino acid.") If this were a real polypeptide, only one of the two structures shown could perform a particular biological function.



1A. 1B.

FIGURE 1: *Two possible arrangements of a polypeptide.*

A diagram of part of a real protein is shown in Figure 2. The figure shows the three-dimensional arrangement of the first 33 amino acids in an enzyme known as carbonic anhydrase. This enzyme catalyzes the reaction

$$H_2CO_3 \overset{\text{carbonic anhydrase}}{\rightleftharpoons} CO_2 + H_2O$$

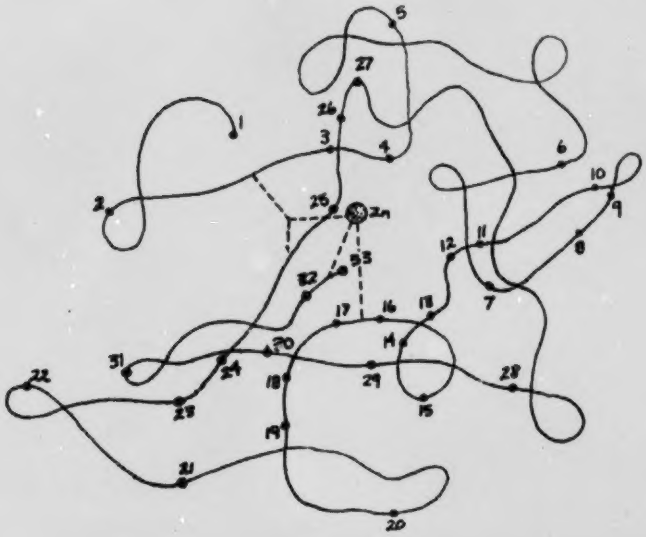


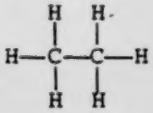
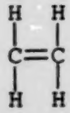
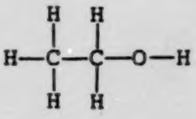
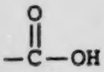
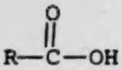
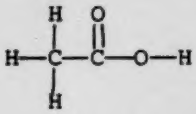
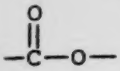
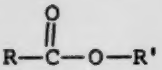
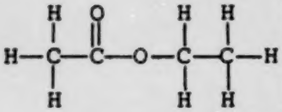
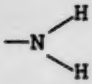
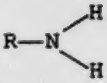
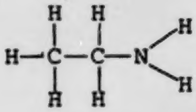
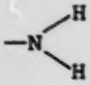
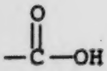
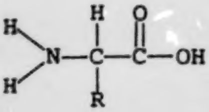
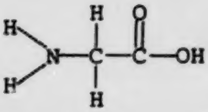
FIGURE 2: *Structure of part of carbonic anhydrase.*

As you may recall, enzymes operate most effectively at a specific pH and at a specific temperature. We can now explain these observations in terms of protein structure. If we change the pH or the temperature of an enzyme, we cause a change in the three-dimensional structure of that protein. As a result, the enzyme and the substrate will not fit together well or will not fit together at all.

Apparently the shape of a protein depends upon numerous weak chemical attractions between its parts. In Figure 1B, note that AA_2 and AA_8 are close together. This may be because AA_2 has an R group with a negative charge while AA_8 has a positively charged R group. Or the two amino acids may be joined by a hydrogen bond just as water molecules form hydrogen bonds. If the temperature is increased a few degrees, the hydrogen bonds may be broken and the protein will change shape and lose its activity. This is called denaturation. Similarly, a change in pH can also change the shape of a protein molecule, thus leading to a decrease or loss of activity.

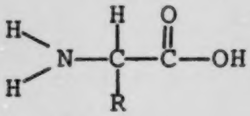
17-4 Review of Organic Chemistry

We have now considered several classes of organic compounds, which are given in the table on the following page. You may wish to refer back to this table from time to time.

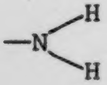
Class Name	Functional Group(s)	General Formula	Example
saturated hydrocarbon			 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$ ETHANE
unsaturated hydrocarbon			 $\underset{H}{\overset{H}{C}}=\underset{H}{\overset{H}{C}}$ ETHYLENE
alcohol	-OH hydroxyl	R—OH	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-O-H$ ETHYL ALCOHOL
organic acid	 $-\overset{O}{\overset{\|\|}{C}}-OH$ carboxyl	 $R-\overset{O}{\overset{\|\|}{C}}-OH$	 $H-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|\|}{C}}-O-H$ ACETIC ACID
ester	 $-\overset{O}{\overset{\|\|}{C}}-O-$	 $R-\overset{O}{\overset{\|\|}{C}}-O-R'$	 $H-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|\|}{C}}-O-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$ ETHYL ACETATE
primary amine	 amino		 ETHYLAMINE
amino acid	  amino and carboxyl		 GLYCINE

Vocabulary:

amino acid (uh-MEAN-oh)--a substance with the general formula



amino group--a functional group consisting of one nitrogen and two hydrogen atoms as shown below.

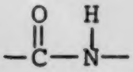


denaturation (dee-NAY-chur-AY-shun)--a change in protein structure accompanied by a loss of biological activity.

dipeptide (dy-PEP-tide)--a molecule formed by the combination of two amino acids.

peptide--a combination of two or more amino acids; if many amino acids are involved, it is described as a polypeptide.

peptide linkage--the group of atoms (shown below) that joins two amino acids in a peptide or protein.



$$-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{N}}-$$

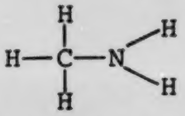
primary amine (uh-MEAN)--a compound consisting of an amino group joined to a hydrocarbon fragment.

protein (PRO-teen)--a large molecule that consists of a chain of amino acids joined by peptide linkages. Proteins are polypeptides, but only large, complex polypeptides are classed as proteins.

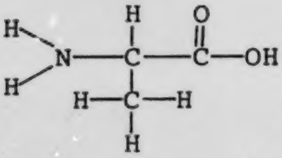
PROBLEM SET 17:

1. Identify carboxyl groups and amino groups in the following compounds. Which compound is a primary amine, and which one is an amino acid?

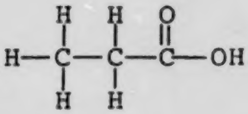
a.



b.



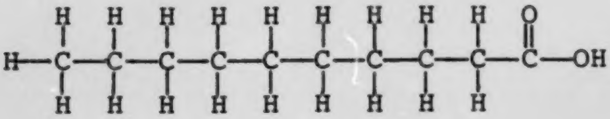
c.



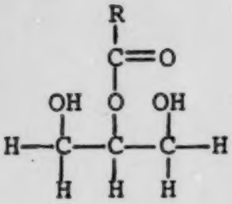
$$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-OH$$

2. Identify in the following group a monosaccharide, a disaccharide, an ester, a saturated fatty acid, an unsaturated fatty acid and an amino acid.

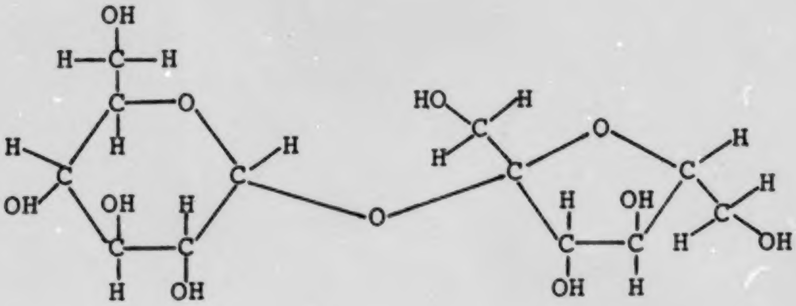
a.



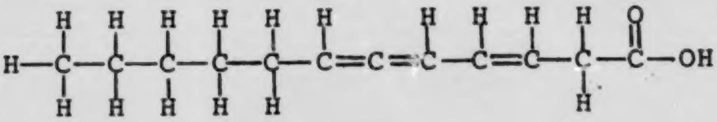
b.



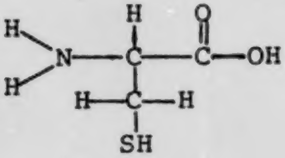
c.



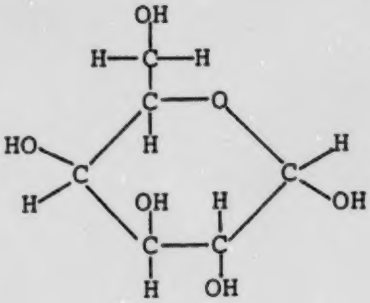
d.



e.



f.



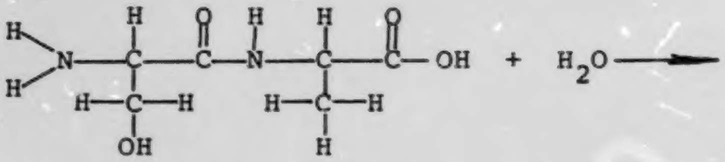
3. Of the molecules in Problem 2:

a. which two are carbohydrates?

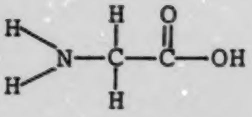
b. which is a building block for proteins?

c. which are produced by the hydrolysis of fats?

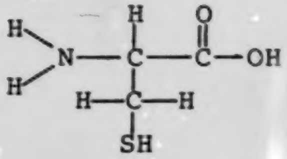
4. Complete the following equation for the hydrolysis of a dipeptide.



5. Draw the structure of two different dipeptides which could be formed from these two amino acids.



and



6. Consider the following substances: glycerol, glycine, lactose, amylase, starch, acetic acid, corn oil.

a. For each of the above except amylase and corn oil, list any functional groups.

b. Which of the substances are organic acids, carbohydrates, alcohols, proteins, fats, amino acids?

c. Which substance is an ester?

d. Which substance contains peptide linkages?

SECTION 18: PROTEINS IN THE DIET

18-1 Protein Requirements

How is the amount of protein we need determined?

Proteins are major components of all the tissues of the body as has been pointed out already. Many of the key chemicals of the body are proteins. Carbohydrates are required mainly for energy, but the primary function of proteins is to build and maintain the structure of the body.

The proteins of the body are made of 20 or so different amino acids. We likened these amino acids to letters and proteins to words. If a word does not contain the correct letters, it is misspelled. If a protein does not include the correct amino acids, it may not be able to perform its functions in the body. For example, a hemoglobin molecule contains about 600 amino acid units. In a condition known as sickle-cell anemia, two of the 600 units are different from those in normal hemoglobin. As a result of this slight difference, red blood cells take unusual shapes (for instance, the shape of a sickle) when they are deprived of oxygen. These distorted cells break up easily; a result is that the oxygen-carrying capacity of the blood is diminished.

Most of the amino acids are synthesized by our bodies in sufficient quantities. But eight amino acids, and more in growing children, are not and must be supplied in our diets. These eight are the essential amino acids; it is essential that they be included in our diets.

Animal protein contains amino acids in approximately the proportions required by our bodies. (This is not surprising, since we are, after all, animals.) Proteins which contain enough of all the essential amino acids to be able to support human life are called complete proteins. Sources of complete protein include meat, fish, eggs and dairy products.

Most vegetables, fruits and grains are not as desirable as sources of protein, because the distribution of amino acids is not as good. Peas and beans, for instance, supply adequate amounts of many amino acids, but relatively little tryptophan and methionine. These are essential amino acids, and a person whose diet contained no other protein sources than peas and beans could develop a deficiency of tryptophan and methionine.

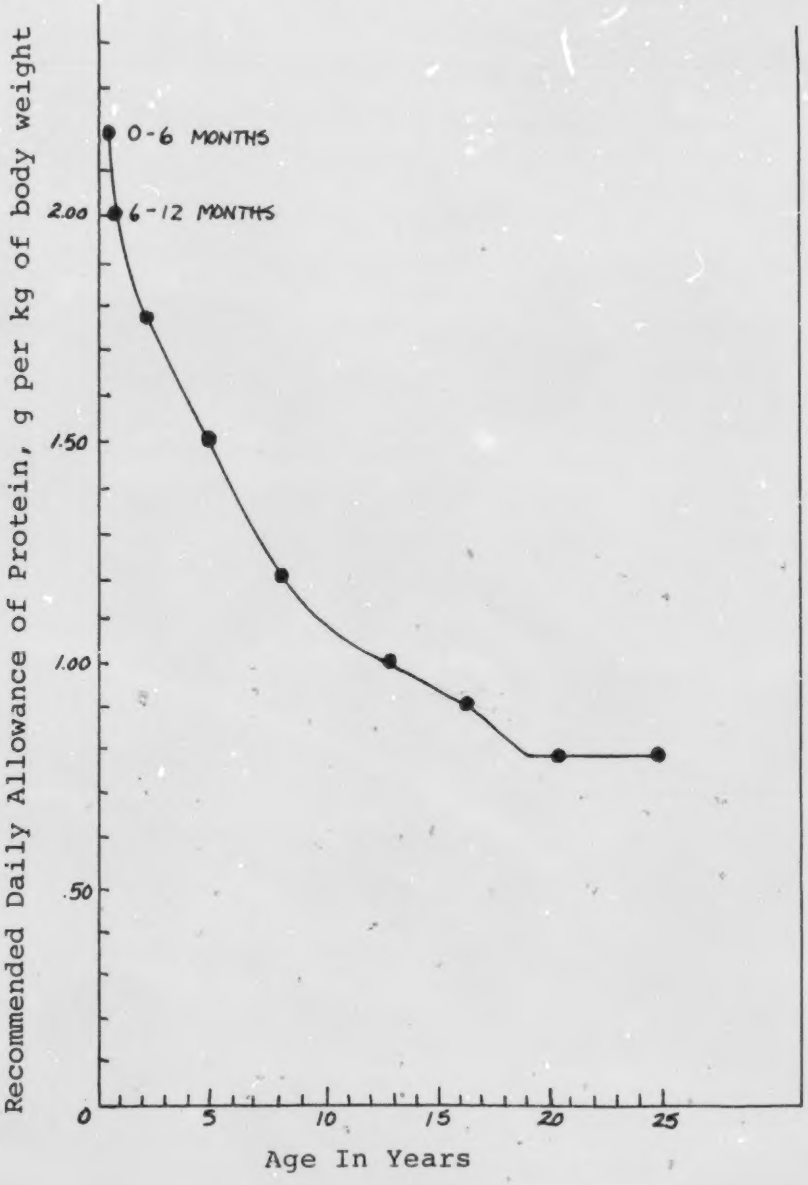
Proteins with small amounts (or none) of one or more essential amino acids are said to be incomplete proteins. The protein in peas and beans is incomplete because of the shortage of tryptophan and methionine. But although most vegetables do not supply complete protein, they nevertheless make a significant contribution of the amino acids they do provide.

Cells in our bodies are continuously dying and must be replaced. All cells contain protein, and our primary need for protein is to build new cells. Children need more protein in relation to their weights than adults do since children's bodies must not only replace old cells, but produce new cells for growth. Even adults require some protein for growth; hair and fingernails, for example, are made mostly of protein.

Protein that is broken down in the body is converted to other substances and lost in urine, feces and sweat. Studies have been made in which the amounts of protein lost in these ways have been determined. The results of these studies have been used to establish the protein requirements of the body. In addition, the amount of protein needed for growth has been determined.

Information from these studies, however, gives only the minimum protein requirements for average individuals of various ages. To provide a margin of safety and to take account of the fact that people differ to some extent in their needs, the minimum requirements are increased substantially. The result is called the recommended daily allowance (RDA).

The following graph shows the RDA of protein from birth to age 25. Note that the quantities of protein are expressed as grams of protein per kilogram of body weight. The values given (which include the margin of safety just discussed) should be adequate for practically all healthy individuals. Ages beyond 25 years are not shown, because once growth stops the need for protein remains constant throughout the remainder of life.



Notice that the need for protein is highest in the first months of life and declines steadily over time until growth ceases. This may be somewhat surprising when one considers the large amount of growth that takes place in the early years of adolescence. If we think about growth in terms of percentage increase in body weight, however, the reason for the steady decline in the need for protein becomes clear. In the first year of life, body weight increases by 100 per cent or more. Over the four-year period from 12 to 16, the body weight typically increases by 50 per cent or less. This is roughly equivalent to a weight gain of 10 per cent per year.

To show how the graph may be used, we will take the examples of a 10-year-old body with a body weight of 34 kg and a young woman of 19 who weighs 55 kg. From the graph, we find

age 10: 1.1 g protein per kg body weight

age 19: 0.8 g protein per kg body weight

$$\left(\frac{1.1\text{ g}}{\text{kg}}\right)(34\text{ kg}) = 37\text{ g} \qquad \left(\frac{0.8\text{ g}}{\text{kg}}\right)(55\text{ kg}) = 44\text{ g}$$

To meet such requirements is not difficult for most people. For example, 44 grams of protein can be obtained from five glasses of milk, from two quarter-pound hamburgers, from six ounces of cheese or, of course, from combinations of these foods or other protein sources.

Although a graph is useful in understanding the relation between age and the need for protein, RDA's are more often shown in tabular form, where the ages are given as ranges. Such a table would provide information of the following kind.

age 15 to 18: 0.9 g protein per kg body weight

age 19 or more: 0.8 g protein per kg body weight

Why are certain amino acids said to be "essential?"

What is an incomplete protein?

Why must protein be included in the diet?

Which is the better source of protein--meat or vegetable?

Compare the protein requirements of an infant and an adult.

What is the protein RDA for a 32-year-old linebacker who weighs 315 pounds?

Vocabulary:

complete protein--a protein that supplies sufficient amounts of all eight essential amino acids.

essential amino acid--an amino acid that is required in greater quantity than the body can manufacture and therefore must be supplied by the diet.

incomplete protein--a protein that supplies only small amounts of one or more essential amino acids.

SECTION 19: MINERALS

What are minerals and what functions do they have in our bodies?

Ninety elements occur naturally on the earth. Of these 90, over 20 are needed by some type of living thing or another. About 20 are known to be needed by man. They are needed for growth and for the maintenance of good health.

Carbohydrates, fats and proteins contain the elements carbon, hydrogen and oxygen. In addition, all proteins contain nitrogen and most contain sulfur. But our bodies need other elements as well. These other essential elements are called minerals.

The word "mineral" is used in various ways, so we will explain how we will be using it. In geology, a mineral is a specific substance with a characteristic crystal structure. For example, apatite, which has the formula $Ca_5F(PO_4)_3$, is a mineral to a geologist. However, in nutrition we say that calcium and phosphorus are minerals. This does not mean that you should include uncombined phosphorus in your diet; the white form of phosphorus ignites in the air at room temperature and is otherwise very toxic. In fact, your body is able to digest, absorb and use phosphorus only if it occurs in certain compounds, such as phosphates. We use the word "mineral" to mean an element that is required by our bodies and that must be obtained from our diets. Phosphorus is a mineral, because our diets must include phosphorus-containing substances that our bodies can use to obtain phosphorus for their needs.

Many of the processes of the body involve electrical charges and depend on the presence of positively or negatively charged ions. The fluids of our bodies, including blood, are in many ways like sea water; in sea water, the most abundant cations are sodium (Na^+), magnesium (Mg^{+2}), calcium (Ca^{+2}) and potassium (K^+), and the most common anion is chloride (Cl^-). Chloride is also the most prevalent anion in our body fluids. Within our cells, K^+ and Mg^{+2} are the most abundant cations; in the fluids outside the cells, Na^+ and Ca^{+2} are the most abundant cations.

The concentration of these ions in our bodies is important in the movement of water by the process of osmosis, and as charged particles they are an important part of the transmission of electric impulses in the body.

Of the elements classed as minerals, we need at least 100 milligrams per day of six: sodium, calcium, magnesium, potassium, chlorine and phosphorus.

When phosphorus was first identified in urine in 1669, it aroused interest, because as an element it was known to glow in the dark, burst into flame spontaneously and be very toxic. It was the last thing that scientists expected to find passing through a human being.

However, it is now known that about one per cent of our bodies is phosphorus. Most of this phosphorus is part of the structure of bones and teeth, but the remainder occurs in all other parts of the body. Phosphorus takes part in numerous chemical reactions throughout the body.

The other major mineral constituent of bone is calcium. Approximately two per cent of our bodies is calcium. Ninety-nine per cent of this calcium is found in bones and teeth, the remainder mainly in the blood. Two of the essential functions of calcium outside the bones and teeth are involved with blood clotting and conduction of nerve impulses. Thus two symptoms of calcium deficiency are slow blood clotting and slow movement of nerve impulses.

Since bones and teeth are built of calcium and phosphorus compounds, a deficiency of calcium or phosphorus causes improper bone and tooth structure. These two minerals are especially important to children, whose bones are growing, and to pregnant women. If calcium or phosphorus is not available for its other functions, it is taken from the bones to meet these other needs. This may result in demineralization of the bones. If the deficiency persists, bones eventually become porous and brittle.

Over half of the magnesium in our bodies is found in bones. The remainder is mainly in tissues, such as muscles, and blood, where magnesium typically activates enzymes. Among the processes in which magnesium participates are muscle contraction, regulation of body temperature and production of protein.

Although magnesium is present in a variety of foods, and cases of deficiency have been rare, magnesium has been receiving increased attention from nutritionists lately. One fear is that the use of chemical fertilizers may hinder the absorption of magnesium from the soil by plants.

Our bodies need over 100 milligrams per day of calcium, phosphorus, magnesium, sodium, potassium and chlorine; the other elements are required in smaller quantities. Three of these elements have been studied sufficiently that recommended daily allowances have been established. These elements are iron, zinc and iodine.

We discussed iron in the Respiration Unit as a constituent of hemoglobin, which carries oxygen and carbon dioxide in the blood. An iron deficiency results in a decreased quantity of hemoglobin and thus a decrease in the capacity of the blood to carry oxygen. This condition is called nutritional anemia.

Zinc is needed by the body primarily for enzymes. For instance, two enzymes that contain zinc are carboxypeptidase, involved in digesting proteins, and carbonic anhydrase, which was discussed in Section 17.

Iodine is essential for the proper functioning of the thyroid gland. The thyroid gland consists of two lobes lying on either side of the trachea, connected by a band of tissue that crosses the front of the trachea, just below the larynx. It secretes a hormone called thyroxin, which contains iodine. Thyroxin is carried by the blood to cells throughout the body, where it controls the rate at which energy is produced.

A condition in which the thyroid gland becomes enlarged is known as *goiter*. As long ago as 3000 B.C. the Chinese found that goiter could be treated by eating seaweed or burnt sponge. Only within the past few hundred years, though, have scientists learned that iodine is the ingredient in seaweed that is effective against goiter. Much of the credit goes to an American physician named David Marine. In 1905, Marine became interested in the discovery that iodine is present in the thyroid gland and the fact that goiter is more prevalent in areas where the soil contains little iodine. (Soil near an ocean tends to be richer in iodine, which is left by the evaporation of sea water carried over the land by wind. Also, salt obtained from sea water naturally contains iodine.)

Between 1905 and 1916 Marine performed a series of experiments that demonstrated that iodine in the diet makes the occurrence of goiter less common. His work was in large part responsible for the introduction of iodized salt in areas where salt is not naturally iodized, and goiter has become far less common in this country than it once was. However, goiter still does occur in parts of the world where the soil has little iodine and where iodized salt is not available.

The situation is complicated by the fact that, when iodine is deficient, certain foods such as cauliflower and Brussels sprouts (your favorites, no doubt) contribute to the occurrence of goiter. However, these foods are not factors when a diet supplies sufficient iodine, and you should not use this as an excuse for not eating your cauliflower.

Although iodine is required in the diet for good health, researchers have found in the past few years that excessive iodine is toxic. The implication of this research is that people living near the ocean or eating a lot of seafood should *not* use iodized salt.

When nutritionists have studied a nutrient sufficiently, recommended daily allowances are established. Daily requirements for 15- to 18-year-olds for phosphorus, calcium, magnesium, iron, zinc and iodine are given in the table on the following page. Recommended daily allowances for sodium have not been established, because, as we will discuss, the typical problem with sodium is caused by an excess rather than a deficiency. Chlorine is obtained along with sodium from table salt (NaCl), and our requirements may be assumed to be met from this source. Potassium is present in so many foods that again it is assumed that most diets supply sufficient quantities.

	Males, 15-18	Females, 15-18
phosphorus, mg	1200	1200
calcium, mg	1200	1200
magnesium, mg	400	300
iron, mg	18	18
zinc, mg	15	15
iodine, µg	150	115

The remaining minerals are required in only very small amounts (trace amounts) and the needs of the body for them have been discovered only within the last fifty years. Most are metals, such as copper and cobalt. Typically they are components of one or more essential enzymes.

Since these elements are required in only trace quantities, it was hard to prove that we need them. Experiments were performed with rats in which the animals were deprived of all traces of the element--not only in food, but in their water, air and even the material of their containers. In this way, the effect of being deprived of the element could be studied. These experiments obviously cannot be performed on human subjects. The human need for these elements can be proved only by finding them in an essential body chemical, such as enzymes or hormones. In the cases of some of the elements needed in trace amounts by rats, they have not yet been found in the human body, and we can only assume that if rats require these nutrients, we are likely to also.

Why all this work to identify minerals that have never been known to cause deficiency diseases? Well, for one thing, there are uncertainties about the future and the earth's ability to supply food for everyone. It may be that within a generation we will need to rely on nutrients manufactured in laboratories: synthetic amino acids, synthetic fatty acids (unsaturated, hopefully), synthetic vitamins. And it will be necessary that these artificial foods contain every mineral that our bodies need. Or, to look at the brighter side, you may wish to go to Saturn for a 20-year vacation and to take synthetic foods, made as light as possible for space travel. You would like your diet to include not only sufficient calcium and phosphorus, but enough cobalt and copper to keep you going for 20 years. So in order to be prepared for the future, scientists will continue to search for every necessary nutrient.

Coming back to Earth, and the present, there is another good reason for nutritional research. We could be healthier than we are at present. Some change in our diets, the increase or decrease of some nutrients, might lead to improved health. One possibility is that a key to improved health is an element, the need for which we do not yet recognize. Therefore, the study of possible trace minerals continues.

Which elements are major components of bones?

Which minerals are found as ions in the greatest concentration in the blood?

What is a function of iodine in the body? What disease results from iodine deficiency?

Why are nutritionists interested in the elements that are required in trace quantities?

Vocabulary:

anemia (uh-NEE-mee-uh)--decreased ability of blood to carry oxygen, as a result of insufficient hemoglobin.

demineralization (dee-MIN-ur-ul-i-ZA-shun)--removal of minerals from bones and teeth for other functions in the body.

goiter (GOY-tur)--condition in which the thyroid gland becomes enlarged, often due to iodine deficiency.

mineral (MIN-er-ul)--an element required by the body for good health (other than C, H, O, N and S).

thyroid gland (THIGH-royd)--a gland located below the larynx on either side of the trachea, which secretes the hormone thyroxin.

trace--tiny.

SECTION 20: VITAMINS

What functions do vitamins perform in the body?

The period around the year 1900 was one of great interest in biological research. Many ideas that came from this research caused revisions in thinking about health and disease. For instance, studies of the effects of diet on health led to new discoveries about the roles played by many nutrients in the functioning of the body. The ways in which the body uses protein, fat and carbohydrate, as well as minerals, came to be better understood.

Another set of ideas originated in the studies of Louis Pasteur and others, who identified microorganisms, such as bacteria, as the causes of many diseases. The theory that microorganisms cause disease was found to be so useful that scientists tended to use the theory to explain any puzzling disease.

However, certain diseases could not be explained by the microorganism theory. It was found that many of these diseases are related to diet. They occur when a diet is deficient in some type of food, but they can be prevented by including even a small amount of that food in the diet.

One disease that was found to be related to diet is a disorder called beriberi. Beriberi involves nerve damage, which can result in muscular weakness and loss of the sense of touch. It was discovered that individuals with a diet of refined (polished, or white) rice were susceptible to beriberi, but that a small amount of unrefined (brown) rice in the diet prevented beriberi. Some ingredient removed from rice by refining was assumed (correctly) to prevent the disease.

The first known association of diet with beriberi occurred in 1885. A medical officer of the Japanese navy named Takaki determined that beriberi could be avoided by including in the rations of the sailors more vegetables, meat and fish, and less rice.

In 1890 a Dutch physician named Eijkman, working in a prison hospital in Java, recognized a connection between a diet of polished rice and the occurrence of beriberi in the prisoners--and also in chickens that were fed on the prisoners' leftovers. It happened that the chickens were switched from polished rice to brown rice, and Eijkman noticed that symptoms of beriberi disappeared from the chickens. However, Eijkman concluded that the prisoners and the chickens were getting beriberi because of some poison added to the rice in the refining process.

Later, in 1901, a physician named Grijns, who worked at the same hospital, correctly identified the cause of beriberi as the absence of a beneficial substance rather than the presence of a harmful one. He concluded that a substance present in the shell of rice, the brown shell that is removed in refining, prevents beriberi.

By 1911 it was apparent that other substances, in addition to the nutrient that prevents beriberi, must be present for the body to function properly. A Polish-born biochemist named Casimir Funk called these essential substances "vitamines." (The prefix "vit-" is from the Latin word for "life"; at the time it was thought that the substances were amines. Thus the name meant "vital amines." It is now known that only a few are amines, but the name, without the final "e" has lasted.) The substance in brown rice that prevents beriberi was given the name vitamin B.

A vitamin is an organic compound that is required in small quantities for the proper functioning of the body. The vitamins that interest us in our study of nutrition cannot be made in sufficient quantity by the body and must be supplied by the diet. The body requires very small quantities of vitamins--less than 50 grams per year of all of them combined. (One ton of rice hulls, which are the part of rice removed by refining, contain only 5 grams of thiamine.)

The functions of vitamins in maintaining health were discovered before the molecular structures of the substances were known. Therefore the substances were designated by letters: A, B, C, D, etc. Not all vitamins have similarities in their chemical structures and properties, as all proteins, fats and carbohydrates do. Vitamins are grouped together mainly because of the similar roles they play as nutrients.

Soon after the discovery of the relation between beriberi and the substance removed from rice during refining, other symptoms were found to be related to diet. The scientists who found these relations were working in many parts of the world and with people with a variety of diets. However, all of these symptoms were originally attributed to a deficiency of vitamin B.

The reports of these scientists were so diverse that it became apparent that vitamin B was actually several vitamins. These vitamins were given the names B_1, B_2, etc., and are now collectively called the "vitamin-B complex." The vitamins in the B complex are related only in that they are all water soluble and occur in many of the same foods. More than a dozen B vitamins have been identified. Three which have been known about and studied for a relatively long time are thiamin, niacin and riboflavin. More recently other B vitamins, such as folic acid, biotin, pyridoxine and pantothenic acid, have been discovered.

The first steps in learning about a nutrient are (1) identifying the foods in which it occurs and (2) determining the effect on the body of a deficiency. The next step is identifying the substance--isolating it and determining its chemical structure.

Dr. R. R. Williams spent 26 years isolating and studying the vitamin whose deficiency causes beriberi, vitamin B_1, before he was finally able to identify it as a compound which he named thiamin. Having identified the vitamin, he was then able to achieve his final goal by synthesizing thiamin in 1936.

We suggested that some vitamins were "discovered" around the year 1900. But some primitive societies had existed for centuries without showing vitamin deficiencies. Presumably, these societies had traditional diets that contained adequate amounts of all vitamins. Such societies were able to survive partly because their diets, known to be adequate, did not change.

Vitamin deficiencies have become most pronounced when a way of life has suddenly changed, and with it the diet. The diets of sailors on long ocean voyages in the fifteenth and sixteenth centuries were different from any previous European diet. Fresh fruits and vegetables were not available to the early explorers for months at a time.

As a result, the crews of these explorers were regularly victims of scurvy. Scurvy is a disease in which the gums bleed and teeth fall out. In extreme cases, death may occur. Ghost ships were occasionally found with their entire crews dead of scurvy.

During the eighteenth century a British physician named James Lind made the important discovery that scurvy could be prevented by including citrus fruits in the diet of sailors. The authorities in London failed to appreciate Lind's discovery and it was soon forgotten, but a generation later the fact that scurvy is related to diet was rediscovered by the British captain, James Cook, during his exploration of the Pacific. Cook attributed the fact that none of his crew suffered from scurvy to the inclusion of sauerkraut in their diet. Soon limes and other citrus fruits were included in the diet of British sailors--thus the name "Limeys."

Dr. Lind and Captain Cook did not identify the substance that prevents scurvy; they only determined that it was an ingredient of certain foods. (This was enough, because it enabled Cook to far outrange rival explorers, who were forced to turn back because of the illness of their crews.) When the term "vitamin" was coined early in this century, the name "vitamin C" was given to the substance that prevents scurvy. The molecular structure of the substance was later determined and it was named "ascorbic acid." Vitamin C and ascorbic acid are the same substance.

The B vitamins and vitamin C are soluble in water. Other vitamins, A, D, and E, are insoluble in water but are soluble in fat. Therefore, they are carried through the body in the lymphatic system along with fats.

When a vitamin has been identified and the substance isolated, its function in the body may be studied. One function of vitamin A is well known. You have perhaps heard that carrots are good for night vision. This is true. Carrots, as well as many other fruits and vegetables, contain the substance carotene. The body converts carotene to vitamin A, and an essential part of the pigment in the the eyes responsible for night vision is synthesized from vitamin A.

Vitamin D is needed by the body for the absorption of phosphorus and calcium from the intestines. It is also needed for the conversion of phosphorus occurring in organic compounds into inorganic phosphates. (Bones require phosphorus, but can use it only in the form of phosphates.) If any one of the three nutrients, vitamin D, calcium or phosphorus is lacking, bones are affected. In a growing child the bones do not develop properly, and the result is a deformed skeleton. This condition is called rickets. The same deficiency in adults leads eventually to the bones becoming soft, a condition known as osteomalacia.

If a patient is suffering from rickets or osteomalacia, the diet could be deficient in vitamin D, phosphorus or calcium. To determine which nutrient is deficient, it is necessary to analyze the patient's diet.

Vitamin D can be formed in the skin by sunlight, thus the name "sunshine vitamin." Ultraviolet rays from the sun cause a chemical reaction in the skin in which certain fat-related substances are converted to vitamin D. (One of the substances is cholesterol, which appeared as a villain in a previous section.) Fish liver oil is an excellent source of vitamin D. The American Medical Association decided to recommend that one food that is consumed by most children be fortified with vitamin D. The choice was milk, and one quart of most milk that is sold commercially now has enough vitamin D added to supply a person's daily needs.

Since vitamin D is created by the body in the presence of sunlight, it may seem that a deficiency of the vitamin is unlikely. However, many people are not exposed to sufficient sunlight. Infants, people restricted to bed for long periods, people who work at night and sleep during the day or people who work underground may obtain insufficient sunlight. Smog may contribute to a vitamin D deficiency by screening out sunlight.

The complex functions of vitamin D in the absorption of calcium and phosphorus are understood, but the function of vitamin E is not. The small amounts of vitamin E assumed to be required by the body, and the possibility of its interacting with other nutrients, make experimentation difficult. Small amounts of vitamin E occur in a wide variety of foods. However, the vitamin is often removed during food processing; for instance, wheat germ is a rich source of vitamin E, but the germ is removed from wheat during refining.

A deficiency of vitamin E is known to cause sterility in both male and female rats, but there is no evidence that it causes sterility in humans. Many claims have been made for the powers of vitamin E in regard to reproduction, but most scientists doubt these claims. In reality, vitamin E deficiencies are a rarity. However, some studies indicate that vitamin E protects the membranes of red blood cells. A prolonged deficiency can lead to breakdown of these cells and anemia.

The symptoms of extreme vitamin deficiencies, such as beriberi, rickets and scurvy are dramatic, but slight deficiencies occur more frequently in contemporary America. Mild deficiencies of B vitamins are often difficult to recognize by their symptoms. The same symptoms may exist for other reasons and are not easily traced to a vitamin deficiency.

Thiamin plays a role in our cells in providing energy, and this may explain one of the symptoms of a mild deficiency: fatigue. Other symptoms are constipation, loss of appetite, irritability and muscle cramps.

Riboflavin takes part in chemical reactions that are necessary to maintain tissue, and a lack of riboflavin can cause damage to many types of tissues. A slight deficiency may be indicated by eyes that are oversensitive to light. A more serious deficiency may cause itching, burning eyes, a red and swollen tongue and cracked lips.

Niacin is essential to obtaining energy from protein, fat and carbohydrate and to synthesizing proteins and fats within our bodies. A mild deficiency is often not recognized because the symptoms may be mental disorders: nervousness, fatigue and depression. Other symptoms are dermatitis (inflammation of the skin) and diarrhea.

Not all of the functions for which ascorbic acid (vitamin C) is needed by our bodies are understood. One that is understood, however, is its role in the formation of a protein called collagen, which holds cells together. A deficiency of vitamin C causes skin to bruise easily and wounds to heal poorly. Patients are sometimes given ascorbic acid after surgery to help an incision heal properly. A few scientists believe that vitamin C, in large daily doses, helps to prevent colds.

What vitamin is removed from rice when it is processed?

What disorder is caused by a lack of this vitamin in the diet?

Are the B vitamins grouped according to chemical structure? What are some of the B-complex vitamins?

Why were British sailors given citrus fruits? What disease did this prevent?

State one function of vitamin A and the effect of a deficiency.

State one function of vitamin D and the effect of a deficiency.

Vocabulary:

beriberi (BEAR-ee-BEAR-ee)--a disorder involving nerve damage, caused by thiamin deficiency.

osteomalacia (OS-tee-o-muh-LAY-see-uh)--a condition of soft bones in adults caused by a deficiency of vitamin D, calcium or phosphorus.

rickets--a condition of defective bone growth in children caused by a deficiency of vitamin D, calcium or phosphorus.

scurvy--a disease caused by prolonged vitamin C deficiency in which the gums bleed and teeth fall out.

vitamin--an organic compound that is required in small quantities for maintenance of health.

SECTION 21: VITAMINS AND MINERALS IN THE DIET

21-1 Minerals in the Diet

Which minerals are most often deficient in the American diet?

The 20 or 30 elements required by our bodies must be supplied by our diets. From proteins, fats and carbohydrates we obtain carbon, hydrogen, oxygen, nitrogen and sulfur; but the other elements needed, called minerals, must be supplied as well.

Over periods of many generations, different cultures have developed traditional diets. Without a scientific knowledge of nutrition, people followed these diets on the assumption that what was good for their grandparents was good for them. In many cases, they may have been right; although there is certainly historical evidence of various kinds of dietary deficiencies.

Are American diets traditional ones? The answer for most Americans is, "No." Even when a diet appears to be similar to that of our grandparents, there are usually many differences. Foods today are more highly processed than in the past, and many nutrients are removed during processing. The American diet, as with most other aspects of our culture, is changing rapidly with time.

As we change our eating habits to new ones, it becomes especially important to examine our diets to see that they are providing us with adequate amounts of all nutrients. Thanks to the labors of many researchers over a long period of time, the information is available to do this.

Potassium and chlorine are present in such a variety of foods that they are rarely a nutritional problem. Phosphorus usually occurs with protein, so a diet adequate in protein presumably provides enough phosphorus. Iodine is generally obtained from iodized salt. The problem with sodium in our diets, as we will shortly see, is more often too much rather than too little. Magnesium may be deficient if too much is removed during food processing.

Calcium and iron are the minerals most commonly deficient in American diets. Canned fish, such as tuna, salmon and sardines, contains calcium in the form of ground bones. Beans and leafy green vegetables are other good sources of calcium. But the principal sources of calcium in our diets are milk and milk products such as cheese and ice cream, and many Americans who do not drink milk or eat dairy products may suffer calcium deficiency. A quart of milk supplies almost the entire daily requirement of calcium. However, milk has disadvantages as a food in that it supplies not only calcium, but sugar and fat as well.

One quart of milk contains 48 grams of the disaccharide lactose. This quantity of sugar, when combined with sugar from other dietary sources, may be more than a healthy diet should contain. A quart of milk also contains 34 grams of fat, which in terms of fatty acids breaks down to 20 grams saturated, 12 grams monounsaturated and only 2 grams polyunsaturated. Thus the ratio of polyunsaturated to saturated fatty acids is very poor. Low-fat milk and other dairy products are preferable because a significant amount of the fat has been removed, and non-fat products are even better. However, in both cases the sugar still remains.

Calcium deficiency affects blood clotting, nerve impulses and bone formation. Excess calcium in the diet is not absorbed in the intestine because of homeostatic control by hormones. Therefore, excess dietary calcium is not thought to cause medical problems.

Nutritional anemia occurs most commonly as a result of iron deficiency. A slight anemia is common in women because of blood loss during menstruation (due to hemoglobin loss). Sometimes pregnant women and people on severe low-calorie diets become anemic. Meat and eggs are excellent sources of iron, and anemia sometimes occurs in people who cannot afford, or will not eat, these foods. However, there are other inexpensive foods which are good sources of iron; these include beans, peas and bread that is made from whole grains or enriched. Many fruits are good sources of iron; prunes and raisins, as well as spinach, owe their reputations to their iron content. The recommended daily allowances allow for the fact that only a fraction of the iron contained in food (5 to 10 per cent) is absorbed into our bodies.

Some useful information on several minerals is tabulated on the next page.

21-2 Sodium and Health

Why may too much sodium be unhealthful?

Sodium is another mineral required by our bodies. A minimum requirement has not been established, because the problem with sodium is usually not too little but too much. The average American consumes from three to seven grams of sodium per day, but needs only about one-half to one gram daily.

Most sodium is consumed in the form of table salt, sodium chloride. The atomic weight of sodium is 23 amu; the molecular weight of sodium chloride 58.5 amu. Therefore, one gram of salt contains 23 ÷ 58.5 grams of sodium. Consuming seven grams of sodium each day is equivalent to consuming about 18 grams of salt. Not all of this salt comes out of our salt shaker. Much salt is added during the processing of food. It is important to remember that most processed food, from soups to nuts, includes added sodium chloride.

The hypothesis has been made that a chronic excess of sodium in a diet may contribute to the development of hypertension. Hypertension is the condition commonly known as high blood pressure. The mechanism by which sodium is related to hypertension is not known, but there is evidence to support the hypothesis. Experiments with rats have shown a correlation between sodium and hypertension. A second piece of evidence is that many patients suffering from high blood pressure have experienced a drop in blood pressure when the quantity of sodium in their diets has been restricted. And in a study of 1300 subjects, fewer than 1 per cent of those with low salt intake were found to have hypertension, while 6.8 per cent of people with normal salt intake and over 10 per cent with high salt intake had high blood pressure.

Another interesting relationship between salt and blood pressure comes from Japan. In the northeastern region of that country, an agricultural area, there is a high rate of hypertension and stroke (blood clot in the brain).

MINERAL	FUNCTION	DEFICIENCY	FOOD SOURCES
Calcium	Formation of bones and teeth, essential to blood clotting, nerve impulse conduction	Faulty calcification of bones and teeth	Milk, cheese, canned fish, figs, dark green vegetables, broccoli, beans
Phosphorus	Formation of bones and teeth, necessary for cellular reactions	Improper bone and tooth structure	Meats, fish, poultry, eggs, milk, cheese, grains, legumes
Iron	Part of hemoglobin (oxygen carrier of blood)	Anemia, digestive disorders	Meat, green leafy vegetables, eggs, enriched and whole wheat bread, beans, nuts, dried fruits
Iodine	Formation of thyroid gland hormones which regulate cell reactions	Goiter--swollen thyroid gland	Seafood, iodized table salt
Magnesium	Activates various enzymes	Retarded growth, weakness, irritability of nerves and muscles, heart and kidney damage	Green leafy vegetables, beans, grains, nuts
Zinc	A component of enzymes	Dwarfism, liver enlargement	Oysters and other seafood, liver, wheat germ
Sodium	Regulates passage of water between blood and tissues	Dehydration	Table salt, bread, canned meats and vegetables, soups
Potassium	Required for protein synthesis in cells	Muscular weakness or paralysis	Meats, cereals, milk, fruits, dark green leafy vegetables, tomatoes

Although the body needs only one to two grams of NaCl per day, it was common for persons in these Japanese farm families to consume 20 grams per day. By reducing salt consumption, the incidence of hypertension among children and adults has taken a significant decline. This study, which was conducted on some 6,000 persons, indicates that excess salt is somehow related to hypertension.

Hypertension can be the result of a disease, but for 90 per cent of the occurrences the underlying cause has yet to be established. The condition of about half of those suffering from hypertension is serious enough to cause them to seek medical attention.

High blood pressure may occur when large blood vessels become narrowed as they do when atherosclerosis occurs. Thus, atherosclerosis may result in one kind of hypertension. But more commonly hypertension results from increased resistance to blood flow in small blood vessels. Some studies have indicated that increased sodium in the blood may contribute to this elevated resistance. Whatever the cause of the increased resistance to blood flow, the consequences for the heart are the same; it is forced to pump at a higher pressure in order to circulate the blood to the tissues.

Sodium in the diets of infants is a special problem, because of the large amount of processed food they consume. It has been suggested that excessive salt in the diets of infants may cause them to develop high blood pressure as adults. Too much salt in an infant's food is common in the United States. A quart of cow's milk contains about 600 milligrams of sodium. An infant consuming a quart of milk daily obtains 600 milligrams of sodium per day from this source alone.

Most babies in the United States receive, in addition to milk, supplemental foods consisting of strained meats, eggs, vegetables and fruits. Although strained fruits contain almost no sodium, 100 grams of strained meat may contain up to 360 milligrams of sodium, while 100 grams of strained vegetables contain an average of 250 milligrams of sodium. Thus an infant consuming a quart of milk plus 100 grams of strained meat or vegetables obtains about one gram of sodium. This is a common diet for a five-month-old baby who weighs about 15 pounds. This one gram of sodium for a 15-pound baby is equivalent to ten grams of sodium for a 150-pound adult.

Another diet that includes a large quantity of sodium is the so-called "soul food" diet. "Soul food" owes its characteristic taste to huge amounts of salt and the way it is cooked. Much of the food is salty when purchased: pickles, pig's feet, salt pork and sausages, to list some examples. Other foods, such as grits, greens and okra, are not naturally salty, but are prepared with salt or salt pork to give them the "soul" taste.

A black American is more likely to suffer from high blood pressure than a white American. This may be caused by a genetic predisposition to the disorder, or by the particular stresses that black people experience. However, it seems likely that the amount of sodium is at least a contributing factor in this disease among people who eat "soul food."

21-3 Vitamins in the Diet

How can we obtain sufficient vitamins in our diets?

If the purpose of eating were simply to obtain enough protein, fat and calories, we could live on four quarts of ice cream every day. Although this might seem like fun, there are reasons for eating what dieticians call a "balanced" diet--a diet that contains meat, dairy products, grains (either as bread or as cereal), vegetables and fruits. A balanced diet is recommended not only because it provides variety, but because different minerals and vitamins are obtained from different foods. By eating a wide variety of foods we obtain a broad spectrum of nutrients.

Very little vitamin C occurs in dairy products or grains and almost none in meat. However, many fruits and vegetables are rich in vitamin C. The following table indicates the milligrams of vitamin C per 100 grams of a few foods. (The RDA for vitamin C is 45 mg for teenagers and adults.)

	$\frac{\text{mg vitamin C}}{\text{100 g food}}$
green peppers	128
oranges	50
grapefruit	38
tomatoes	23
milk	1
bread	0
hamburger	0

Often an orange color in foods is indicative of the presence of vitamin A. This vitamin is found in various vegetables and fruits, and also in liver, egg yolks and butter. Margarine and milk are commonly fortified with vitamin A. Quantities of vitamin A are measured in International Units (IU), rather than the usual mass units. The next table gives the amounts of vitamin A in a few good sources. [The RDA for vitamin A is 4000 IU for females and 5000 IU for males (teenagers and adults).]

	$\frac{\text{IU vitamin A}}{\text{100 g food}}$
beef liver	43,900
carrots	11,000
sweet potatoes	8,800
spinach	8,100
butter and fortified margarine	3,300
apricots	2,700

Many of the B vitamins occur in grains, such as rice and wheat. It was stated that beriberi was caused by a lack of thiamin. Processing rice and removing the shell indirectly brought about beriberi in people who depended heavily upon this staple.

Riboflavin occurs in a wide variety of foods. Good sources are brewer's yeast, milk, cheese, leafy vegetables, eggs, lean meats, grains, beans and chili pepper. Only pure sugars and fats are entirely lacking in thiamin and riboflavin. Storage and preparation of food may destroy riboflavin as well as other B vitamins. Riboflavin is destroyed by light, so that bread stored in a clear wrapper and milk stored in a transparent bottle can lose a significant amount of riboflavin if exposed to sunlight. Cooking a vegetable for too long a time can destroy vitamins. And since B vitamins are soluble in water, if a food is cooked in too much water and the water then poured off, most of the B vitamins are poured off with the water.

The B vitamin, niacin, occurs in most of the foods that are good sources of thiamin and riboflavin, such as whole or enriched grains and meats. An interesting point about niacin is that our bodies can produce niacin from the essential amino acid tryptophan. Thus if a diet is low in tryptophan, more niacin is needed.

A balanced diet should contain sufficient amounts of all the B vitamins. Yet nutritional problems can still occur if vitamins are lost in food processing by the manufacturer or the cook. In view of this problem, you may wonder why grains are refined. Perhaps the white color of refined grains and flour is associated with higher quality, because in the past, only rich people could afford the more expensive, highly milled grain products. Another reason is that refined grain is easier to store, because rodents and insects generally do not eat it; they prefer unprocessed grains and coarsely milled flours. Maybe the rats know more than we do!

It should be pointed out that products made from refined grain, such as white bread and flour, are enriched. But of the various vitamins and minerals lost during refinement, only a few are returned by the process of enrichment.

Vitamin pills are manufactured that are intended to supply the daily allowance of all vitamins. These pills may provide a person with all the vitamins he needs, but we can't be sure of this. The possibility exists that foods contain some vitamins that we do not yet know about. A person should supply his daily vitamin needs with food rather than vitamin pills.

Information on vitamins is summarized in the accompanying table.

VITAMIN	FUNCTION	DEFICIENCY	RDA 15-18 years of age	FOOD SOURCES
Vitamin B_1 (Thiamin)	Necessary for oxidation of carbohydrates	Beriberi	females: 1.1 mg males: 1.5 mg	Dry yeast, wheat germ, pork and organ meats, whole grain or enriched breads and cereals
Riboflavin	Required for utilization of food to obtain energy and synthesis of fats and proteins	Tissue damage (e.g., cracking of lips), eye strain and fatigue, itching, sensitivity to light	females: 1.4 mg males: 1.8 mg	Organ meats (e.g., liver), milk, green leafy vegetables, cheese, beans
Niacin		Scaly pigmented dermatitis on areas exposed to sun; anemia is also frequent	females: 14 mg males: 20 mg	Meat, poultry, fish, whole and enriched grains
Vitamin C (ascorbic acid)	Necessary for formation of collagen (protein substance that holds cells together)	Scurvy	45 mg	Citrus fruits, strawberries, melons, turnip and mustard greens, cauliflower, cabbage, broccoli, green peppers, tomatoes
Vitamin A	Maintains skin, mucous membranes, bone and visual pigments	Rough, dry skin, night blindness, dry mucous membranes	females: 4000 IU males: 5000 IU	Liver, carrots, apricots, egg yolk, butter, margarine, green and yellow vegetables, milk
Vitamin D	Necessary for calcium and phosphorus absorption and normal bone growth	Rickets, osteomalacia	400 IU	Salmon, sardines, tuna, milk, liver, butter; can be synthesized in the skin with exposure to sunlight

21-4 Hypervitaminosis

Can we get too much of a vitamin?

Excesses of water-soluble vitamins are removed from our bodies in urine, but fat-soluble vitamins such as A and D are stored in our bodies. A condition caused by an excess of a vitamin is called hypervitaminosis.

Excess quantities of vitamin A usually result from taking vitamin supplements. Hypervitaminosis A causes drowsiness, headache and vomiting. Recent studies have indicated that symptoms of mental disease can be produced by excess vitamin A.

The RDA of vitamin A is 4000 to 5000 IU for adults. Ten times this amount taken over a period of time can kill infants; daily doses over 100,000 IU for a period of time have killed adults.

Eskimos have long avoided eating polar bear livers. Early explorers in the Arctic were warned not to eat polar bear livers by the Eskimos. Some explorers did not listen. Unfortunately these explorers died from vitamin A poisoning. While the Eskimos could not have known that polar bear liver contains an extremely large quantity of vitamin A, they recognized that people who ate these livers died.

Large quantities of vitamin D also have bad effects. Twenty-five times the required amount taken for several weeks causes vomiting and diarrhea, and also causes calcium to be withdrawn from the bones.

Hypervitaminosis does not often occur. It sometimes occurs with infants or adults taking vitamin supplements, but is not likely when vitamins are obtained only from foods.

A current controversy in science concerns large doses of vitamin C, ascorbic acid. Vitamin C has been claimed to prevent that disease which has so successfully resisted medical science, the common cold. The man who first made the claim is Dr. Linus Pauling. Dr. Pauling is a chemist who received the Nobel Prize in 1954 for his work in theoretical chemistry and again in 1962 for his effort to achieve world peace! His chemical work acted as a catalyst to the research of scientists studying the structure of proteins and other biochemicals.

The recommended daily allowance of ascorbic acid is 45 milligrams for adults. Dr. Pauling suggests that by taking 1 to 2 grams per day, colds may be prevented. Pauling, his wife and several friends have been taking 3 to 10 grams of vitamin C daily for up to thirty years. During that time they have had very few colds. Pauling has conducted further studies himself and refers to other research which has been done that supports his position.

Other scientists, however, have disputed Pauling's claims. Although there is no evidence to prove that ascorbic acid does not prevent colds, Pauling's work has been attacked on two grounds. One is that he has not studied enough cases to obtain meaningful results--scientists are more willing to accept conclusions from clinical studies when the number of cases is large. The other objection is that the long-range effects on our bodies of such large doses of the vitamin are not known. For example, the effect on pregnant women of taking large doses of vitamin C is not known. Do the systems of the infant adjust to the high level of the vitamin? Will the newborn child immediately develop a vitamin C deficiency? These and many related questions are yet to be answered.

Is such controversy harmful to science? Would it be better if scientists always agreed? Certainly not; if scientists always agreed, there would be little scientific progress. New scientific discoveries often contradict old beliefs. Constructive disagreement is the base on which much of science has grown. Disagreement allows both sides to be evaluated by the entire scientific community. If a new hypothesis passes this test, it is accepted by the community. If not, its backer may return to his research and seek a better idea.

What are some minerals that may be short in our diet? What minerals are likely to be in excess?

What nutrients are supplied by milk? What are the disadvantages of whole milk as a food?

Why do spinach, raisins and prunes have the reputation of being "good for you?"

What is meant by hypervitaminosis?

What hypothesis has been made associating excess sodium with health? What evidence supports this hypothesis?

What foods are good sources of vitamin C? Of vitamin A?

How can food processing affect the quality of a food?

Vocabulary:

hypertension (HY-pur-TEN-shun)--high blood pressure.

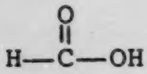
hypervitaminosis (HY-pur-VY-tuh-min-O-sis)--a condition caused by too much of a vitamin.

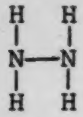
REVIEW SET 21:

1. What distinguishes an organic compound from an inorganic compound? Which of the following are organic and which inorganic?

a. C_2H_6O

b. NaCl

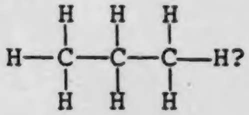
c. 
$\mathrm{H{-}\overset{\overset{O}{\|}}{C}{-}OH}$

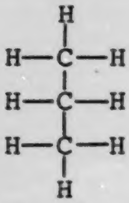
d. 
$\mathrm{\overset{H}{\underset{H}{N}}{-}\overset{H}{\underset{H}{N}}}$

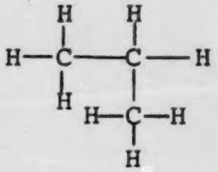
e. vitamin C

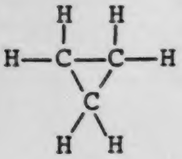
f. calcium phosphate

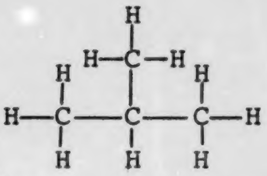
2. Explain what is meant by hydrogen bonding. Name one nutrient in which hydrogen bonding occurs.

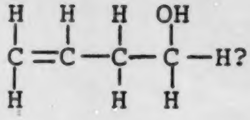
3. Which of the following are identical to 
$\mathrm{H{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}H}$?

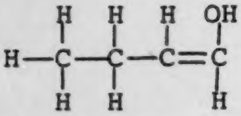
a. 

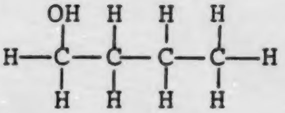
c. 

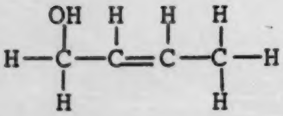
b. 

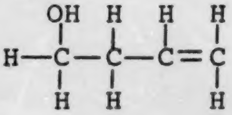
d. 

4. Which of the following compounds are isomers of 
$\mathrm{\overset{H}{\underset{H}{C}}{=}\overset{H}{C}{-}\overset{H}{\underset{H}{C}}{-}\overset{OH}{\underset{H}{C}}{-}H}$?

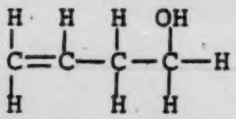
a. 
$\mathrm{H{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{C}{=}\overset{OH}{\underset{H}{C}}}$

c. 
$\mathrm{H{-}\overset{OH}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}H}$

b. 
$\mathrm{H{-}\overset{OH}{\underset{H}{C}}{-}\overset{H}{C}{=}\overset{H}{C}{-}\overset{H}{\underset{H}{C}}{-}H}$

d. 
$\mathrm{H{-}\overset{OH}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{C}{=}\overset{H}{\underset{H}{C}}}$

5. Which of the compounds in Problem 4 is identical to


$$\underset{H}{\overset{H}{C}}=\overset{H}{C}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{OH}{C}}-H$$

Which compounds are saturated and which are unsaturated?

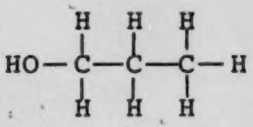
6. Draw structural formulas of

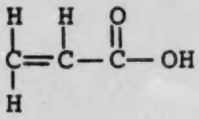
a. a hydroxyl group,

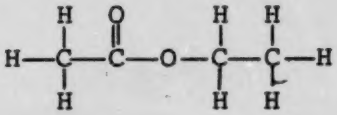
b. a carboxyl group,

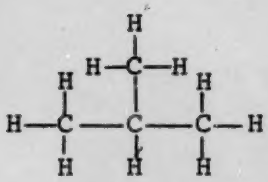
c. an amino group.

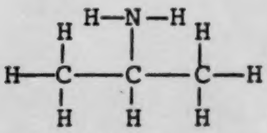
7. Identify among the following molecular structures a hydrocarbon, an alcohol, an acid, an ester and an amine. Also state which of the compounds contain a hydroxyl group, a carboxyl group, an amino group.

a.

$$HO-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$$

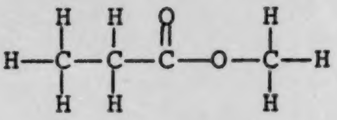
d,

$$\underset{H}{\overset{H}{C}}=\overset{H}{C}-\overset{O}{\overset{\|}{C}}-OH$$

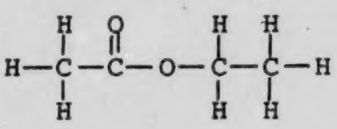
b.

$$H-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-O-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$$

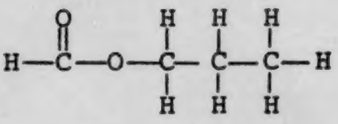
e.

$$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H-\overset{H}{C}-H}{C}}-\underset{H}{\overset{H}{C}}-H$$

c.

$$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H-N-H}{C}}-\underset{H}{\overset{H}{C}}-H$$

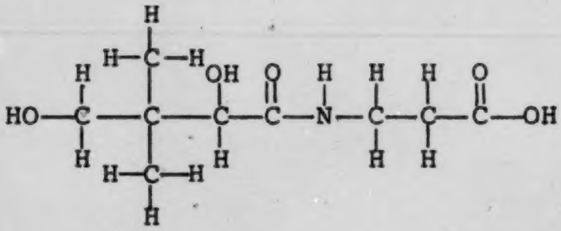
8. Which of the following is the product of a dehydration synthesis involving CH_3OH and C_2H_5COOH?

a.

$$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-O-\underset{H}{\overset{H}{C}}-H$$

c.

$$H-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-O-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$$

b.

$$H-\overset{O}{\overset{\|}{C}}-O-\underset{H}{\overset{H}{C}}-\ \underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$$

9. One of the B-complex vitamins is pantothenic acid. Its structural formula is



Which of the following are contained in the pantothenic acid molecule?

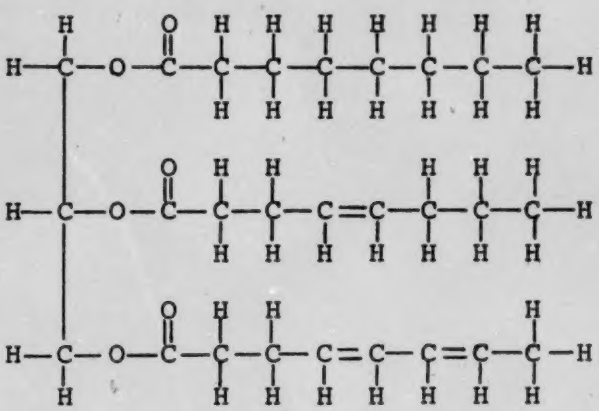
a. a hydroxyl group

b. a carboxyl group

c. a peptide linkage

d. an amino group

10. Draw the structural formulas of the three fatty acids formed in the hydrolysis of the following fat.



Which of the three fatty acids is preferable as a nutrient? Explain.

11. Define the following terms.

a. essential amino acid

b. complete protein

c. denaturation

12. Identify each of the following types of reactions as true or false.

a. fat → 3 fatty acids + glycerol

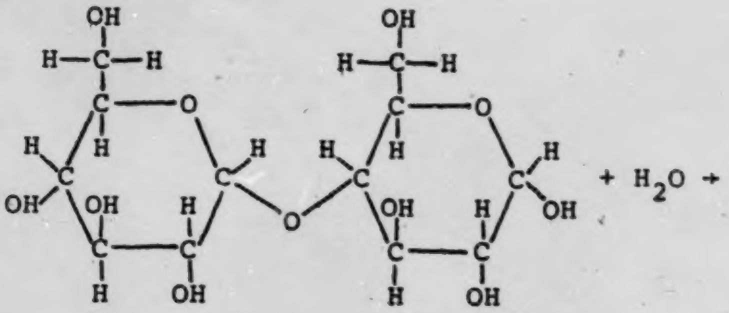
b. disaccharide + disaccharide → protein

c. dipeptide → monosaccharide + amino acid

d. monosaccharide + monosaccharide → disaccharide

Of those that actually occur, identify each as being either a hydrolysis or a dehydration synthesis.

13. Complete the equation for the hydrolysis of maltose.



This reaction will take place only in the presence of

a. any enzyme,

b. a lipase,

c. a carbohydrase,

d. a proteinase.

Where do hydrolysis reactions take place in the body?

14. Are glucose and starch digested at the same rate? Does the rate of digestion matter? Explain.

15. Which one of the following nutrients is deficient in a diet of meat, bread and whole milk? (Refer to the text, if necessary.)

a. protein

b. calcium

c. vitamin C

d. potassium

Which of the following symptoms would you expect to appear if this diet were followed indefinitely?

e. anemia

f. bleeding gums and loose teeth

g. soft and brittle bones

h. low blood sugar

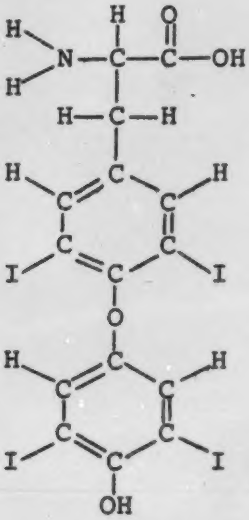
i. atherosclerosis.

Name a food that could be added to the diet to correct this deficiency.

16. Which of the following must be obtained directly from the diet because the body cannot synthesize sufficient amounts for its needs?

a. essential amino acids
b. vitamin B_1 (thiamin)
c. vitamin C
d. glycogen
e. phosphorus
f. iodine
g. magnesium

17. The molecular structure of the hormone thyroxin is



a. What functional groups are contained in a thyroxin molecule?

b. Identify thyroxin as either an amino acid, a fatty acid or a carbohydrate.

c. What mineral is required by the body to synthesize thyroxin?

SECTION 22: ENERGY

22-1 Nutrition and Energy

What is most of the food we eat used for?

We have seen that the function of the respiratory system is to supply oxygen to the cells of the body and to remove carbon dioxide. We have also discussed the function of the digestive system--to provide a variety of nutrients to the cells. We will soon see how the two functions are related.

In the previous sequence (Sections 10-21) we examined nutrients and saw that some, such as proteins, calcium and phosphorus, are used to build and replenish the bones and tissues of our bodies. Many vitamins and trace minerals are parts of enzymes that need to be replenished. Other minerals exist as ions in the body's fluids.

However, the largest part of the food we digest each day is not used for body structure, nor is it used for enzymes or hormones or ions. Most of the food we eat is used simply for fuel.

What is the function of a fuel? The fuel you may burn in your house keeps it warm. The fuel that burns in your automobile makes it move down the road. And that, stated as simply as possible, is what the products of digestion do in our bodies: keep us warm and keep us moving.

Heat and motion are both forms of something we call energy. Energy, like length, mass and time, is one of the important concepts of physical science. This and the next two sections will be devoted to the idea of energy.

Energy is measured in units called calories; knowing this and knowing that food is used to provide our bodies with energy, it is clear why "calories" is a word associated with nutrition.

How do cells obtain energy from food? Stated in the simplest way, cellular energy is obtained by the chemical reaction of glucose (provided by the digestive system) and oxygen (supplied by the respiratory system).

glucose + oxygen → carbon dioxide + water + energy

The functions of the respiratory system in supplying oxygen and the digestive system in providing fuel have long been known, but the way oxygen and the products of digestion combine to produce energy have begun to be understood only recently. Indeed, the unraveling of the chemistry that takes place within cells is one of the great achievements of 20th-century science. Sections 25 through 26 are devoted to this topic.

In our discussions of chemical reactions, we have assumed that they occur, without asking why they occur, how rapidly they occur and whether all reactants are converted to products. These questions may be approached through the idea of equilibrium, which is introduced in Section 27.

By that time you will have learned enough about how nutrients serve the body's needs to enable you to examine your own diet to see whether it is adequate for your needs. A few of the activities that you will be doing are (1) determining your energy requirements by calculating your energy expenditure for a typical day, (2) calculating the calorie content of your diet and comparing this to your energy output and (3) determining the quantities of some essential nutrients in your diet and comparing these amounts to your daily requirements.

These comparisons will allow you to design the best possible diet that fits your needs (and your tastes). We will call this an optimal diet. If your optimal diet and your present diet are not the same, which one will you follow?

22-2 Energy

What are some of the forms that energy takes?

In everyday language, "energy" means the capacity for doing something, in the sense that we say, "He lacks the energy to do the job." However, scientists have given the word a more specific definition. The definition may not be very helpful in understanding energy, so we will also try to describe the concept and give examples of various forms that energy may take.

Energy is usually defined in terms of work, but scientists also use the word "work" differently than you do. A physicist says that you are doing more work when you throw a ball than while you read this book. He does not say this because he prefers reading this book to playing ball, but because he defines doing work as giving energy to an object.

Recall that in the Respiration Unit you determined your physical fitness by the aerobic step test. You stepped repeatedly onto a platform and calculated your work rate. The work done in each step up was the product of your weight and the distance you lifted it against the force of gravity (the height of the platform). The work was expended in raising your body to a new height. Your body acquired potential energy, and potential energy has the potential to become energy of motion.

Energy of motion is called kinetic energy. When you throw a ball, you give the ball kinetic energy. Therefore you do work on the ball. When you lift a box onto a table, a task you and the physicist would agree upon as work, you are giving the box potential energy, or stored energy.

What do we mean by stored energy? Suppose you carelessly placed the box over the edge of the table so that when you let the box go, it fell back to the floor. When you lifted the box you did work on the box; you gave energy which was stored as the potential energy of the box. When you let the box go, the stored energy was converted to kinetic energy, the energy of motion of the box as it fell (see Figure 1, opposite).

When the box is on the table it owes its potential energy to the gravitational attraction of the earth. Gravitational potential energy is one form of potential energy. Another form is elastic potential energy. You do work when you stretch a rubber band or compress a spring. Before you release the rubber band, its energy is stored as elastic potential energy. When you do release it, the potential energy is converted to kinetic energy.

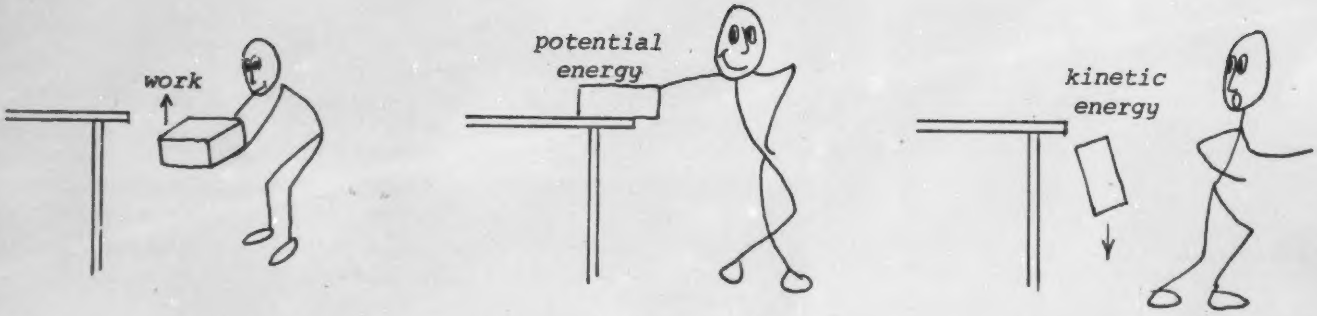


FIGURE 1: *Work, potential energy and kinetic energy.*

Another type of potential energy is electric energy. When a negatively charged object is brought near a positively charged object, the potential energy is converted to kinetic energy; the objects move toward each other. Nuclear energy, the energy stored in the nuclei of atoms, is yet another form of potential energy. What is this stored energy converted to when an atomic bomb explodes?

While we are discussing forms of energy, we should mention radiant energy. Radiant energy is exemplified by light and other forms of radiation, such as infrared, ultraviolet and X-rays. The earth obtains energy from the sun in the form of radiant energy.

A less obvious form of energy is heat. From your study of gases, you know that when a gas is heated, its molecules move more rapidly. Heating a gas increases the kinetic energy of the molecules. Heating a liquid or solid also increases the motion of atoms; the atoms of a solid and liquid vibrate more rapidly about their positions. Heat is the kinetic energy of individual particles: molecules, atoms or ions.

However, heat differs from the kinetic energy of a moving body in one important respect. The particles of a moving body all move in the same direction with the same speed. Heat, by contrast, is random motion of particles--particles moving in different directions at different speeds.

Until the 1800's heat was thought to be a form of matter, a substance like air and water. Heat was measured in units of calories, while energy was measured in other units. But a variety of experiments showed that the amount of kinetic energy lost because of friction is proportional to the amount of heat generated by friction. Furthermore, the development of the steam engine demonstrated that heat can be converted to kinetic energy. Thus heat took its place as a form of energy, as one kind of kinetic energy.

Confusion sometimes exists about the difference between heat and temperature. The confusion exists because when heat is added to a substance, its temperature increases.

Your experience is that temperature is a measure of "hotness." This is true, because what you sense as "hotness" is molecules striking your skin, and temperature is a measure of the average kinetic energy of individual molecules. The greater the kinetic energy of molecules, the faster they move and the hotter they feel.

When we say "average kinetic energy of individual molecules," we mean the total kinetic energy (the heat energy) divided by the number of molecules. Thus heat is closely related to temperature, although at the same temperature two unequal masses of the same substance contain different amounts of heat energy. The average kinetic energy of the molecules in the two samples is the same, but since the larger sample has more molecules, it has more heat energy.

One way to think of temperature is as an indicator of heat flow. If two objects at different temperatures are brought into contact, heat energy flows from the one at higher temperature to the one at lower temperature. If the two objects are at the same temperature, no heat flows between them.

Heat energy is measured in units that are defined in terms of the amount of heat required to raise the temperature of a given amount of water by a certain amount.

The unit called the calorie is defined as the amount of heat required to raise the temperature of a gram of water by one Celsius degree. For example, ten calories can raise the temperature of ten grams of water by one Celsius degree, or they can raise the temperature of one gram of water by ten Celsius degrees.

Another unit, the kilocalorie, is the amount of heat required to raise the temperature of a kilogram of water by one Celsius degree. Thus one kilocalorie is equal to 1000 calories.

EXAMPLE:

How much heat energy in calories is required to raise the temperature of 200 g of water from 60 °C to 80 °C? How many kilocalories?

SOLUTION:

We use the notation ΔT for the temperature change.

$$\Delta T = 80 - 60 = 20\ ^\circ C$$

One calorie is required to raise the temperature of 1 g of water by 1 °C. Therefore, the heat energy (H) required to raise the temperature of x g by ΔT degrees is given by

$$H = x\Delta T$$

$$H = (200)(20)$$

$$= 4000 \text{ calories}$$

$$4000 \text{ calories} \times \frac{1 \text{ kilocalorie}}{1000 \text{ calories}} = 4 \text{ kilocalories}$$

Units of calories and kilocalories, originally intended to measure quantities of heat, are often used to measure other forms of energy as well.

22-3 Chemical Energy

Among the products of digestion are monosaccharides, fatty acids and amino acids. When these substances react with oxygen, energy is released. Where does this energy come from?

The energy comes from chemical bonds, where it is stored in a form called chemical energy. Whenever a chemical reaction occurs, bonds are formed and broken; and either another form of energy is converted to and stored as chemical energy, or chemical energy is released as another kind of energy.

Gasoline is a mixture of hydrocarbons. The hydrocarbon molecules have energy stored as chemical energy. When a mixture of gasoline and air is ignited in an automobile engine by a spark, a chemical reaction occurs. Chemical energy is converted to other forms of energy. One form is heat; another is kinetic energy--as in the motion of the automobile.

Food likewise contains energy stored as chemical potential energy. The use of food by the body as a source of energy is in many ways analogous to the use of gasoline by an automobile. In both cases fuel is oxidized, more vigorously in the automobile, more gently in the body. And the body uses the energy obtained more efficiently; more is converted to kinetic energy and less to heat.

You may now appreciate that the calorie is not a unit of mass. The misconception arises because energy is stored in the body in the molecules of fat, protein and carbohydrate. And fat is measured as mass, not as energy.

Since the energy that interests us in the study of nutrition is chemical, we will discuss how potential energy is stored in chemical bonds.

Chemical energy may be thought of as a type of electric potential energy. Recall that an atom consists of a positively charged nucleus surrounded by negatively charged electrons which occupy orbitals. An electron is attracted to an oppositely charged nucleus just as a book is attracted to the earth. The book has gravitational potential energy because of this attraction, but as it falls, its potential energy decreases. Likewise an electron has electric potential energy because of its attraction to the nucleus, and if it moves closer to the nucleus, its potential energy diminishes. (See Figure 2 on the following page.)

Electrons in different orbitals have different amounts of potential energy; when an electron moves from one orbital to another, its potential energy changes. Electrons that are part of molecules occupy orbitals, just as electrons do in single atoms, although the situation is more complicated in molecules.

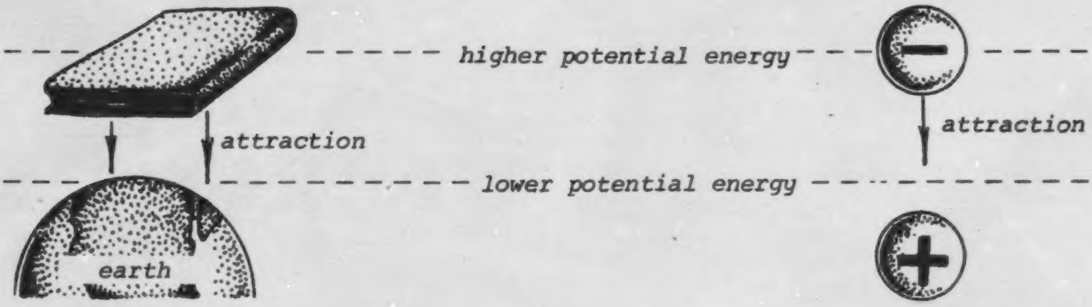


FIGURE 2: *Attraction and potential energy.*

Consider the hydrogen molecule, H_2. Each atom has one electron, which it contributes to the bond.

H:H

An electron is not attracted to just one nucleus; it is attracted to two nuclei (Figure 3). (In addition, the two nuclei repel one another, and the two electrons repel one another.)

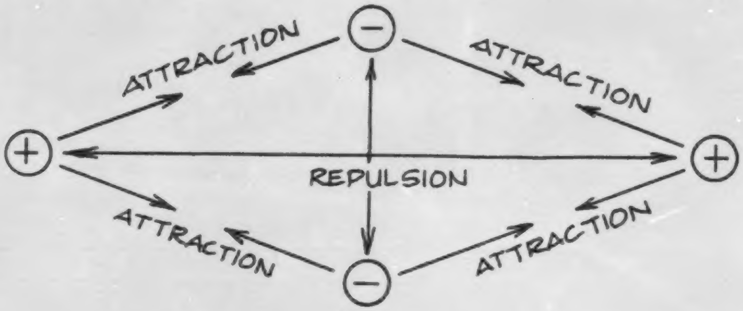


FIGURE 3: *Attraction and repulsion in a hydrogen molecule.*

What is important about this arrangement is that the potential energy of the electrons in a bond between hydrogen atoms is lower than the potential energy of the electrons when they are attached to isolated hydrogen atoms. Therefore, when two hydrogen atoms have the opportunity, they go to a situation of lower potential energy by combining to form a hydrogen molecule. The situation is like that of a ball on a hillside; the ball rolls to the bottom of the hill, where potential energy is lowest. (See Figure 4, opposite.)

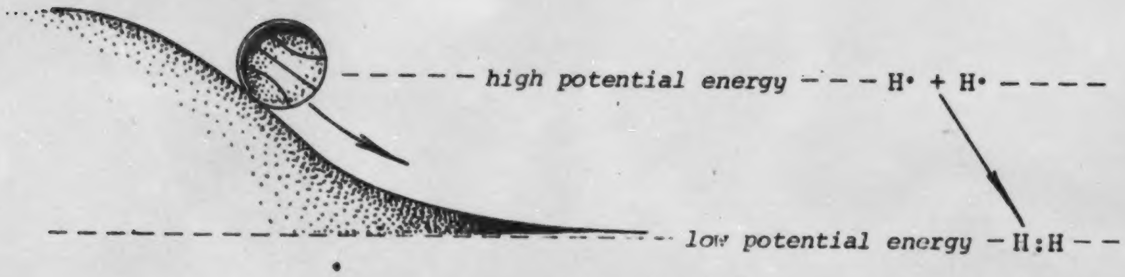


FIGURE 4: *Movement toward lower potential energy.*

The potential energy of a rolling ball is converted to the kinetic energy of its motion; the potential energy of combining hydrogen atoms may be released in a number of ways, such as radiant energy or heat.

The release of energy by the formation of a bond between hydrogen atoms is typical of chemical reactions in which bonds are formed. When a bond is formed, energy is released.

But in chemical reactions bonds are not only created; they are also broken. When a bond is broken, energy must be obtained by the molecule. When a ball is carried to the top of a hill, work is done on the ball; the ball is given gravitational potential energy. When a chemical bond is broken, work is done on the electrons; the electrons are given energy which they store in the form of chemical potential energy (Figure 5).

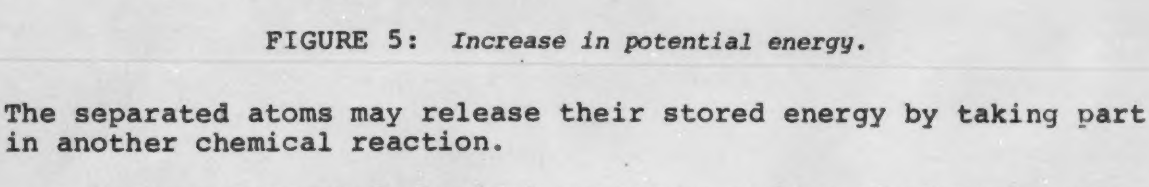


FIGURE 5: *Increase in potential energy.*

The separated atoms may release their stored energy by taking part in another chemical reaction.

We have presented chemical energy as a form of electric energy. This is only a slight oversimplification. Chemical energy is basically electric energy on an atomic scale.

This discussion of the theory of chemical energy is an introduction to the topic of the next section, which concerns the quantity of energy released or absorbed during a chemical reaction.

Distinguish between kinetic energy and potential energy.

List several types of potential energy.

Distinguish between heat and temperature.

Define the term "calorie."

When a ball is thrown straight up, at what point does it have maximum potential energy? Maximum kinetic energy? Minimum potential energy?

How much energy is required to heat 12 grams of water from 20 °C to 30 °C?

Describe the conversions of energy from one form to another when an automobile burns gasoline.

Vocabulary:

calorie--the amount of energy required to raise the temperature of one gram of water by one Celsius degree.

chemical energy--the potential energy, essentially electric, stored in chemical bonds.

energy--the capacity to perform work.

heat--the kinetic energy of individual molecules, atoms or ions.

kilocalorie--the amount of energy required to raise the temperature of one kilogram of water by one Celsius degree.

kinetic energy--the energy of motion.

potential energy--stored energy.

temperature--a measure of the average kinetic energy of individual molecules, atoms or ions.

work--the effort required to move an object. If an object is moved straight upward against the force of gravity, the work done on the object is the product of its weight and the height to which it is raised.

SECTION 23: RELEASE AND CONSERVATION OF ENERGY

23-1 The Energy of Chemical Reactions

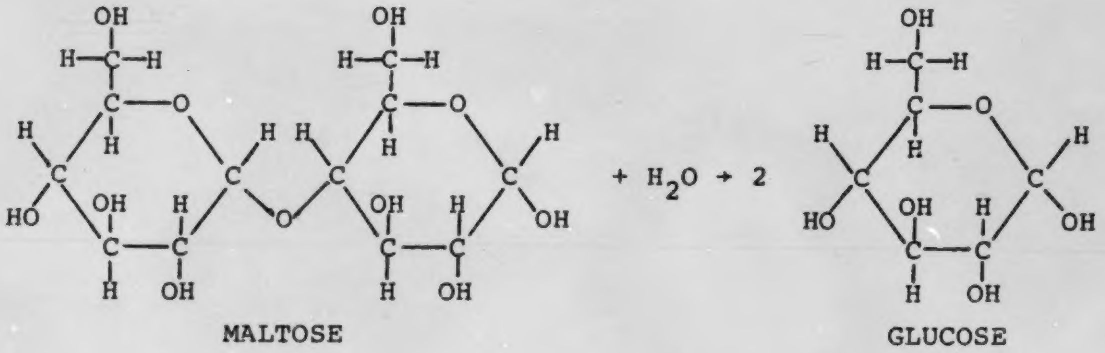
How is the change in energy during a chemical reaction expressed?

The purpose of this sequence is to see how our bodies obtain energy from the food we eat. We have stated that this energy is obtained by the chemical reactions of products of digestion. But how do such reactions release energy?

When chemical bonds are formed, energy is released. When bonds are broken, energy is absorbed. However, most chemical reactions involve both breaking bonds and forming new bonds. The amount of energy released in breaking bonds and the amount absorbed in forming bonds are seldom equal. Therefore the end result may be either absorption of energy or release of energy during the reaction.

For the present we will treat the energy that is absorbed or given off as heat. If the energy released by the formation of new bonds is greater than the amount needed to break existing bonds, heat is given off during the reaction, and the reaction is said to be exothermic. But if the breaking of bonds requires more energy than that released in forming new bonds, heat is absorbed during the reaction, and the reaction is endothermic.

Consider the hydrolysis of maltose to form glucose. In this reaction, two bonds are broken as the maltose and water molecules split. Two new bonds are formed as the H and OH fragments from H_2O join the maltose fragments to form glucose molecules.



When one molecule of maltose hydrolyzes to form two molecules of glucose, 7×10^{-24} kilocalories of energy are released. This is a very small quantity of energy and a very small quantity of matter. For these reasons the energies involved in a chemical reaction are given not in terms of molecules but in terms of moles. The energy released in the formation of two moles of glucose from maltose and water is

$$\left(7 \times 10^{-24} \frac{\text{kcal}}{\text{molecule}}\right) \left(6 \times 10^{23} \frac{\text{molecules}}{\text{mole}}\right) = +4.2 \frac{\text{kcal}}{\text{mole}}$$

Since heat is released, the reaction is exothermic. The fact that heat is released in the reaction indicates that the reactants had more stored energy than the product does. One mole of maltose and one mole of water contain 4.2 kilocalories more energy than two moles of glucose do.

Suppose we let $H_{reactants}$ be the energy stored in the reactants and $H_{products}$ be the energy stored in the products. The energy released or absorbed in a reaction is the difference between the energy stored in the products and the energy stored in the reactants.

In Biomedical Mathematics you have used a convenient notation for expressing the difference between two quantities, the symbol Δ (delta). We may use this symbol to write the difference in energy between the products and reactants in a chemical reaction.

$$\Delta H = H_{\text{products}} - H_{\text{reactants}}$$

The amount of heat energy absorbed in a reaction is called the heat of reaction. Thus ΔH is the heat of reaction and is usually written ΔH_r. If H_{products} is greater than $H_{\text{reactants}}$, heat is absorbed and ΔH_r is positive. But if H_{products} is less than $H_{\text{reactants}}$, heat is released and ΔH_r is negative. Thus the sign of ΔH_r indicates whether heat is absorbed or released in a reaction.

Since energy is released, rather than absorbed, in the hydrolysis of maltose, the heat of reaction for this reaction is a negative quantity.

$$\Delta H_r = -4.2 \ \frac{\text{kcal}}{\text{mole}}$$

It is important to remember how heat of reaction is defined: if energy is absorbed, the heat of reaction is positive; if energy is released, the heat of reaction is negative. Heat of reaction is defined from the point of view of the molecules involved in a reaction. If the molecules gain energy during the reaction, the heat of reaction is positive; therefore $\Delta H_r > 0$ for endothermic reactions. If molecules lose energy during the reaction, the heat of reaction is negative; therefore $\Delta H_r < 0$ for exothermic reactions.

A chemical equation may be written to include the heat of reaction. But if the reaction is exothermic, the energy appears as a positive number on the right side of the equation. Thus the equation for the formation of glucose by the hydrolysis of maltose is

$$\text{maltose} + \text{water} \rightarrow 2 \text{ glucose} + 4.2 \text{ kcal}$$

The equation may be interpreted to mean that the reaction of one mole of maltose with one mole of water produces two moles of glucose and 4.2 kilocalories of energy.

When a heat of reaction is negative, as in an exothermic reaction, it appears as a positive number on the right side of the reaction equation. When a heat of reaction is positive, as it is for an endothermic reaction, the number on the right side of the equation is negative.

A source of confusion may be the units "kilocalories per mole." When a reaction equation is written as above, the heat of reaction refers to the reaction of one mole of maltose and one of water to produce two moles of glucose. Per mole of glucose,

$$\Delta H_r = \frac{1}{2} \times (-4.2) = -2.1 \text{ kcal}$$

This fact may be expressed by writing the reaction equation either in the form

$$\frac{1}{2} \text{ maltose} + \frac{1}{2} \text{ water} \rightarrow \text{glucose} \qquad \Delta H_r = -2.1 \frac{\text{kcal}}{\text{mole of glucose}}$$

or in the form,

$$\frac{1}{2} \text{ maltose} + \frac{1}{2} \text{ water} \rightarrow \text{glucose} + 2.1 \text{ kcal}$$

23-2 Conservation of Energy

What happens to energy that is expended? Is it lost?

Throughout this sequence we consider energy as though it were a type of money or currency. Energy is "stored"--in balls on slopes, in chemical bonds--as money is stored in banks. It is "converted"--from potential to kinetic, for instance--and it is "expended." We may discuss energy in these terms because it is conserved. Indeed, the Law of Conservation of Energy is one of the fundamental laws of physics. We will illustrate the idea of conservation by an example.

Imagine a ball placed at the top of a slope. Because of its position the ball has gravitational potential energy. We will say it has 20 units of energy, all potential. It has no kinetic energy because it is not yet moving (see Figure 1).

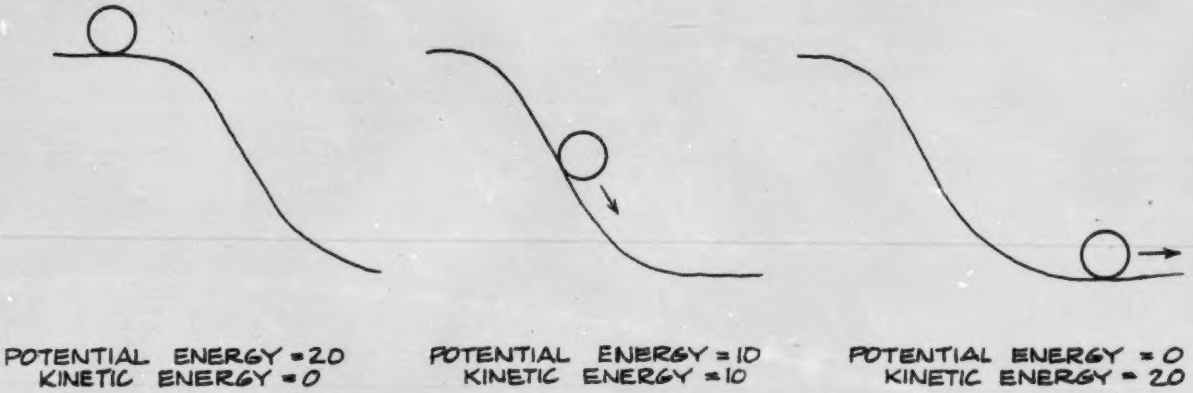


FIGURE 1: *Conversion of potential energy to kinetic energy.*

The ball begins to roll. When it is halfway down the slope, it has only half as much potential energy, 10 units. But it now has kinetic energy, because of its motion. The amount of kinetic energy it has is 10 units.

The ball continues to go faster as it rolls to the bottom of the slope. When it reaches the bottom it has no potential energy, but it has 20 units of kinetic energy.

If the ball rolls along the bottom and encounters an upward slope, it will begin to roll up that slope (Figure 2).

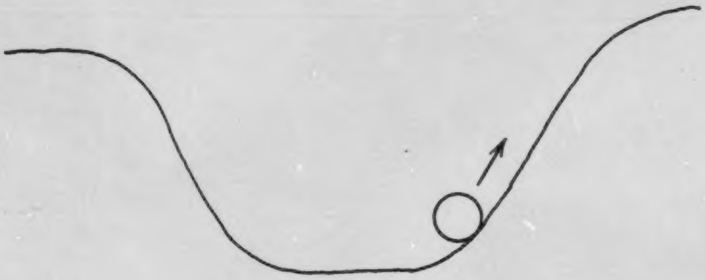


FIGURE 2: *Conversion of kinetic energy to potential energy.*

How far? As it rolls up the slope, kinetic energy is converted to potential energy. When all the kinetic energy has been converted to potential energy, the ball stops. It stops for an instant; then it rolls back down.

If all 20 units of energy became potential energy, the height the ball would reach on the right-hand slope would be the same as the height at which it began on the left-hand slope. However, not all kinetic energy is transformed to potential energy. As the ball rolls it encounters resistance in the form of friction, and some of the ball's energy is converted to heat. If the ball is allowed to roll back and forth between the slopes indefinitely, its energy is gradually converted to heat. Eventually the ball comes to rest at the bottom, where it has no potential energy and no kinetic energy. But 20 units of energy have not been destroyed; they have been converted into a different form of energy, heat. We say that energy has been conserved, meaning that the total amount of energy has not changed.

The story of the ball illustrates the Law of Conservation of Energy. This law states that energy can neither be created nor destroyed.

This law is true of all processes, not only the conversion of gravitational potential energy into kinetic energy. When a rubber band is stretched, it is given elastic potential energy. When it is released, the potential energy is converted to an exactly equal amount of kinetic energy and heat energy. When gasoline burns in an automobile engine, the chemical potential energy of the fuel is converted to an exactly equal amount of kinetic energy and heat.

(When scientists discovered that in nuclear reactions matter may be converted to energy, they did not abandon the Law of Conservation of Energy--rather they included matter as a form of energy!)

People have been becoming increasingly concerned about an energy crisis. You have no doubt heard that we are running short of sources of energy. But if energy is conserved, if it is neither created nor destroyed, how can we run short of energy? The answer is that energy that is converted to heat is not always usable. In that sense energy which is converted to heat is lost, because it is inefficient to convert heat back to other forms of energy. Each time we use the chemical energy of fuels or foods, we convert some of that useful energy into heat. And the supply of fuels and foods is limited. It is in this sense that our supplies of energy are running "low."

23-3 Conservation of Energy in Chemical Reactions

What happens to chemical energy during a series of chemical reactions?

Energy is stored in the bonds of a maltose ($C_{12}H_{22}O_{11}$) molecule. Much of this energy may be converted to heat by reacting maltose with oxygen as follows.

$$C_{12}H_{22}O_{11} + 12\ O_2 \rightarrow 12\ CO_2 + 11\ H_2O + 1350.2\ \text{kcal} \qquad (1)$$

The reaction is exothermic; ΔH_r is -1350.2 kilocalories per mole of maltose. The energy stored in one mole of maltose plus 12 moles of O_2 is 1350.2 kilocalories more than that stored in 12 moles of CO_2 and 11 moles of H_2O.

$$H_{C_{12}H_{22}O_{11}} + H_{12\ O_2} = H_{12\ CO_2} + H_{11\ H_2O} + 1350.2\ \text{kcal}$$

The energy stored in maltose may be released in other ways also. In Section 23-1 we used the example of the hydrolysis of maltose to glucose ($C_6H_{12}O_6$) and gave the heat of reaction as -4.2 kilocalories per mole of maltose.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2\ C_6H_{12}O_6 + 4.2\ \text{kcal} \qquad (2)$$

When maltose hydrolyzes, 4.2 kilocalories per mole of its energy and the energy from H_2O is released as heat. Again, energy is conserved, and the remainder of the energy contained in maltose and water is transferred to the glucose molecules that are formed.

$$H_{C_{12}H_{22}O_{11}} + H_{H_2O} = H_{2\ C_6H_{12}O_6} + 4.2\ \text{kcal}$$

In turn, energy can be obtained from glucose by its combustion with oxygen. The reaction is exothermic, and 673.0 kilocalories are given off per mole of glucose reacting.

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 673.0\ \text{kcal} \qquad (3)$$

Equation 3 tells us that one mole of glucose and six of O_2 contain 673.0 more kilocalories than six moles of CO_2 and six of water.

$$H_{C_6H_{12}O_6} + H_{6\ O_2} = H_{6\ CO_2} + H_{6\ H_2O} + 673.0\ \text{kcal}$$

Energy has now been obtained from maltose in two steps. In the first step (Equation 2), a mole of maltose was hydrolyzed to two moles of glucose, releasing 4.2 kcal. The two moles of glucose then reacted (Equation 3) with 12 moles of O_2 to form 12 moles of CO_2 and 12 of H_2O, releasing 2 x 673.0 = 1346.0 kcal. The total energy released per mole of maltose is

$$4.2 + (2 \times 673.0) = 1350.2\ \text{kcal per mole of maltose}$$

Compare this number to the one obtained by directly oxidizing maltose to CO_2 and H_2O (Equation 1). Whether maltose is converted to CO_2 and H_2O directly, or in two steps, 1350.2 kilocalories are given off per mole of maltose. This result is not coincidence. Rather it is the result of energy being conserved in each of the three reactions, and the fact that Equations 2 and 3 combined are equivalent to Equation 1. Quantities are doubled in Equation 3 below to take account of the two moles of glucose formed per mole of maltose.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2\ C_6H_{12}O_6 + 4.2\ \text{kcal} \qquad \text{(Equation 2)}$$

$$\underline{2\ C_6H_{12}O_6 + 12\ O_2 \rightarrow 12\ CO_2 + 12\ H_2O + 1346.0\ \text{kcal}} \qquad \text{(Equation 3)}$$

$$C_{12}H_{22}O_{11} + \cancel{H_2O} + \cancel{2\ C_6H_{12}O_6} + 12\ O_2 \rightarrow \cancel{2\ C_6H_{12}O_6} + 12\ CO_2 + \overset{11}{\cancel{12}}\ H_2O + 4.2\ \text{kcal} + 1346.0\ \text{kcal}$$

(Equation 2 + Equation 3)

$$C_{12}H_{22}O_{11} + 12\ O_2 \rightarrow 12\ CO_2 + 11\ H_2O + 1350.2\ \text{kcal}$$

(Equation 2 + Equation 3 = Equation 1)

Thus the amount of energy released when maltose and oxygen form carbon dioxide and water directly is equal to the amount released when the process occurs in two steps, with glucose as an intermediate product. This equality holds true whenever the final products of a series of reactions are the same as the products of a single reaction. This result of the conservation of energy is important to the study of nutrition, because in our cells the energy content of food is passed from one reaction product to another by means of complex series of reactions.

When bonds are broken in a chemical reaction is energy released or absorbed? Explain.

If a reaction is endothermic, is ΔH positive or negative?

A Biomedical Laboratory Manual is accidentally knocked off a car roof. If the potential energy of the book on the roof is 1.86 calories, what will be the potential energy of the book just before it hits the pavement? What is the kinetic energy just before it hits the pavement?

State the Law of Conservation of Energy.

Is the earth running out of energy? Discuss.

Is energy conserved in chemical reactions? Explain.

Vocabulary:

endothermic (EN-doe-THUR-mik)--referring to a reaction in which heat is absorbed.

exothermic (EX-oh-THUR-mik)--referring to a reaction in which heat is given off.

heat of reaction--the quantity of heat absorbed during a chemical reaction.

PROBLEM SET 23:

1. Excess acidity (H^+ ions) in the stomach may be neutralized by antacids containing bicarbonate (HCO_3^-) ions.

$$H^+ + HCO_3^- \rightarrow H_2CO_3$$

$$\Delta H_r = -1.82 \text{ kcal per mole}$$

a. Is the reaction exothermic or endothermic?

b. Write the heat of reaction as part of the equation.

2. The following equation represents the combustion of methane, but is not balanced.

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

210.8 kilocalories are released by the combustion of one mole of methane.

a. Balance the equation.

b. Is the reaction exothermic or endothermic?

c. What is the heat of reaction of the combustion of methane?

d. Write the heat of reaction as part of the balanced chemical equation.

e. Is more energy contained in the bonds of the reactants or the products?

3. The neutralization of an acid by a base produces water.

$$H^+ + OH^- \rightarrow H_2O$$

A mole of water contains 13.36 fewer kilocalories of energy than the combined energy of a mole of hydrogen ions and a mole of hydroxide ions.

a. Is the neutralization reaction exothermic or endothermic?

b. What is the heat of reaction?

4. The body is able to use galactose ($C_6H_{12}O_6$) as a source of energy by first converting it to its isomer glucose.

$$\text{galactose} \rightarrow \text{glucose} \qquad \Delta H_r = +2.3 \frac{\text{kcal}}{\text{mole}}$$

Glucose can then be oxidized, as we have seen, with the release of 673.0 kilocalories per mole.

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O \qquad \Delta H_r = -673.0 \frac{\text{kcal}}{\text{mole of glucose}}$$

a. Is the conversion of galactose to glucose exothermic or endothermic?

b. If a mole of galactose is oxidized directly to CO_2 and H_2O, what is the change in energy?

c. How much energy can be obtained by the oxidation of one gram of galactose? (Hint: Determine the molecular weight of galactose.)

5. Assume that the octane in gasoline burns completely in an automobile engine to form carbon dioxide and water. The combustion of one mole of octane releases 1303 kilocalories of energy.

$$C_8H_{18} + O_2 \rightarrow CO_2 + H_2O$$

a. Balance the equation.

b. Write the heat of reaction as part of the equation.

c. Is the reaction exothermic or endothermic?

d. If 900 kilocalories per mole of octane are converted to heat, how much energy per mole of octane can become kinetic energy?

e. What is the general principle behind the calculation of Part d?

SECTION 24: ENERGY AND METABOLISM

24-1 Energy and Food

Do the processes within the body obey the Law of Conservation of Energy?

We have illustrated the conservation of energy by describing a rolling ball. The ball was placed at the top of a slope, where it had a certain amount of potential energy. As it rolled down the slope, potential energy was converted to kinetic energy. At the bottom of the slope, the ball had no potential energy; its energy was entirely kinetic.

The amount of energy possessed by the ball was constant throughout; energy was conserved. But where did the ball obtain its energy originally? If the ball began with 20 units of potential energy, someone did 20 units of work on the ball. Someone (or someone's pet dog) expended 20 units of energy.

The person who placed the ball at the top of the slope did not create 20 units of energy. The processes of the body obey the Law of Conservation of Energy just as a rolling ball, a stretched rubber band and an automobile engine do. But whereas an automobile uses the chemical energy of gasoline, the body uses the chemical energy of food.

The oxidation of proteins, fats and carbohydrates is exothermic. That is, energy is released during the reactions. The amount of energy released is measured in units of calories.

The nutritionist's calorie is the same as the physicist's kilocalorie: the amount of energy required to raise the temperature of one kilogram of water by one Celsius degree. From now on we will express quantities of energy in terms of the nutritionist's calorie, abbreviated "Cal". (The capital "C" helps to distinguish the two kinds of calories.) Whenever the word "calorie" is used in reference to food, it will be the nutritionist's calorie.

The exothermic reaction of a nutrient with oxygen is illustrated by the combustion of the monosaccharide glucose, which we encountered in the last section.

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 673\ \text{Cal}$$

The combustion of one mole of glucose releases 673 calories of energy.

How much energy does the body obtain from different nutrients? Energy values of foods are generally expressed in terms of mass of food rather than number of moles of food. So we wish to know the number of calories released by the combustion of one gram of each nutrient. One mole of glucose reacts to provide 673 calories. To find the energy provided by one gram of glucose we must calculate its gram molecular weight.

The atomic weight of carbon is 12 amu, and a glucose molecule contains 6 carbon atoms. Therefore, carbon contributes 12 x 6 = 72 grams to the gram molecular weight. The atomic weight of hydrogen is 1 amu, so the 12 hydrogen atoms per molecule contribute 1 x 12 = 12 grams to the gram molecular weight. Each of the 6 oxygen atoms has an atomic weight of 16 amu; consequently oxygen contributes 16 x 6 = 96 grams to the gram molecular weight. The gram molecular weight of glucose is the sum of the contribution of carbon, hydrogen and oxygen, or 72 + 12 + 96 = 180 grams. One mole of glucose thus has a weight of 180 grams.

180 grams of glucose oxidize to release 673 calories of energy. Therefore, glucose provides

$$\frac{673\ \frac{\text{Cal}}{\text{mole}}}{180\ \frac{\text{g}}{\text{mole}}} \simeq 3.74 \text{ Cal per g}$$

The oxidation of starch provides 4.18 calories per gram. However, the digestion of starch is not completely efficient. About five per cent of starch consumed is undigested and passes through the body without providing energy. Therefore we multiply the number 4.18 by .95 to obtain a more realistic value. The actual energy value of starch is thus 4.18 x .95 ≃ 4.0 calories per gram. We will use the number 4 calories per gram for the energy value of carbohydrates in general. This is the number you have been using in nutritional calculations in Biomedical Mathematics.

Fats also react with oxygen to form carbon dioxide and water and to release energy. The combustion of a mole of the fat tripalmitin is an example of this.

$$C_{51}H_{98}O_6 + 72\tfrac{1}{2}\ O_2 \rightarrow 51\ CO_2 + 49\ H_2O + 7657 \text{ Cal}$$

(tripalmitin)

The molecular weight of tripalmitin is 807 amu. Since the combustion of one mole of tripalmitin releases 7657 calories, the combustion of one gram releases

$$\frac{7657\ \frac{\text{Cal}}{\text{mole}}}{807\ \frac{\text{g}}{\text{mole}}} \simeq 9.48 \text{ Cal per g}$$

This value is typical for the combustion of one gram of a fat. The digestion of fats, like the digestion of carbohydrates, is only about 95 per cent efficient. Therefore, we multiply 9.48 by .95 to obtain the value of approximately 9.0 calories for the energy obtained from one gram of tripalmitin. We will use 9 calories per gram for the energy provided by fats as a group. Note that, gram for gram, fats are much richer in energy than carbohydrates. Fat deposits are the most efficient means of storing energy in the body, since over twice as many calories are stored in a gram of fat as are stored in a gram of carbohydrate or protein. (This is not meant to endorse building energy storage depots of fat--we will treat the health problems associated with obesity soon.)

The chemical reactions for the combustion of proteins are more complicated than the reactions of fats and carbohydrates. This is because there are many different kinds of proteins and they are composed of many different kinds of amino acids and each amino acid is oxidized in a different way. Thus, we will not attempt to write the equation of a protein oxidation.

In addition, the degree of digestibility varies greatly with the kind of protein being digested. While we can digest meat proteins almost completely, we cannot digest plant proteins as well. Only about 70 per cent of the mass of corn proteins is digestible. The accepted practice of nutritionists is to take an average for the energy value of protein of 4 calories per gram.

Note that the energy values of proteins, fats and carbohydrates are only specified to one digit. For example, the energy value of one gram of carbohydrate is given as 4 calories, not as 4.0 calories. Does this tell you anything about the implied uncertainty of the numbers? The numbers are only average values; variations are found between one substance and another. As we determined, glucose does not provide 4.0 calories per gram but 3.74 calories per gram, or less if it is not completely absorbed. In addition, the efficiency of digestion and use of a nutrient varies between individuals. Our values of 4 calories per gram for proteins and carbohydrates and 9 calories per gram for fats are useful numbers, but it must be remembered that the variation from them may be as much as ±.5 calorie per gram in some cases.

To illustrate the use of these numbers and also to demonstrate their uncertainty, let us use them to calculate the energy value of a cup of almonds. A cup of almonds contains 26 grams of protein, 77 grams of fat and 28 grams of carbohydrate.

26 grams of protein provide

$$26 \text{ grams} \times 4 \frac{\text{calories}}{\text{gram}} = 104 \text{ calories}$$

77 grams of fat provide

$$77 \text{ grams} \times 9 \frac{\text{calories}}{\text{gram}} = 693 \text{ calories}$$

28 grams of carbohydrate provide

$$28 \text{ grams} \times 4 \frac{\text{calories}}{\text{gram}} = 112 \text{ calories}$$

The total energy provided by a cup of almonds is the sum of the contributions of protein, fat and carbohydrate.

$$104 + 693 + 112 = 909 \text{ Cal}$$

(You have learned to solve this type of problem in Biomedical Mathematics by using the dot product.)

The energy value of a cup of almonds may also be determined from a food table. USDA Bulletin 72 indicates that 850 calories are actually obtained from one cup of almonds. Our calculated value of 909 calories is too high by almost seven per cent. For most foods, however, the difference is not this great.

24-2 Energy and the Body

What is meant by "metabolic rate?" What is its medical significance?

Our bodies obtain their energy from chemical potential energy stored in foods. This chemical energy is converted into other forms of energy by the reactions of products of digestion with oxygen.

Energy is needed by our bodies not only to lift balls to the tops of slopes and perform other muscular activities; it also is required while we are at rest. Energy is required for breathing, circulating blood, maintaining our body temperature and keeping our brains active. So we even expend energy while we sleep.

The term metabolism refers to two major classes of chemical and physical processes that occur within the cells of our bodies. One of these processes is the building of large molecules from simpler ones (for example, proteins from amino acids). The other process is the release of energy for use in the body by the conversion of large molecules to simpler ones.

The term metabolic rate is used to describe the rate at which we expend energy. The metabolic rate differs depending upon what kind of activity we are engaged in. It is greater for strenuous activities, such as swimming, than it is for sedentary ones, such as watching television.

The amount of energy required for a specific activity is not measured directly. We cannot feed a person 10 grams of glucose and tell him to run around until the energy is used up.

However, a method does exist for estimating the energy we expend. It is based upon the equation for the combustion of a food. Consider again the reaction of glucose.

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 673 \text{ Cal}$$

This equation summarizes the molecular process of respiration. It tells us that when 673 calories are obtained from the oxidation of glucose, 6 moles of oxygen are consumed. At 0 °C and one atmosphere of pressure, a mole of oxygen occupies a volume of 22.4 liters. We can calculate the amount of energy this reaction releases for each liter of O_2 consumed as follows. (We assume here a temperature of 0 °C and a pressure of one atmosphere. If the gas volume is measured at other temperatures and pressures, the volume of one mole of O_2 can be corrected using the gas laws.)

$$\frac{673\ \text{Cal}}{6\ \text{moles}\ O_2} \cdot \frac{1\ \text{mole}\ O_2}{22.4\ \text{liters}} \simeq 5.0\ \text{Cal per liter}$$

Thus when glucose is metabolized, approximately 5.0 calories are produced for each liter of oxygen consumed. The value for starch and carbohydrates in general is 5.1 calories per liter of oxygen consumed. Since it is known how much energy is released by the consumption of one liter of oxygen, the energy required for an activity may be determined by measuring oxygen consumption.

It is also necessary to know what a person has eaten because the number 5.1 calories per liter of oxygen is valid only for carbohydrates. A liter of oxygen reacting with fats produces about 4.7 calories, while a liter reacting with protein provides only about 4.5 calories. It is common to use an average value of 4.8 calories per liter of oxygen for a normal diet.

One medical test involves measurement of the basal metabolic rate or BMR. For this test, the patient is asked not to eat anything for at least 12 hours preceding the measurement. The test involves measuring oxygen consumption while the patient is lying down and as relaxed as possible. Although the word "basal" implies that the test gives the lowest possible rate of energy expenditure, this is actually not the case. The metabolic rate is lowest when we are asleep. Since it is not possible to get patients to sleep on command, the BMR is defined as the lowest possible rate of energy expenditure while the individual is awake. The metabolic rate during sleep is about 90 per cent of the BMR.

The BMR varies among individuals. It varies to some extent with weight, sex and age. It is different for a growing child and an adult, for a sick person and a healthy person. It depends upon temperature and the surface area of the body, since heat loss is related to surface area. And a kilogram of muscle uses more energy than a kilogram of fat tissue does.

Sometimes an increased metabolic rate is caused by excessive secretion of hormones by the thyroid gland (Section 19). This condition, known as hyperthyroidism, is characterized by nervousness, weakness, excessive sweating and restlessness. Another symptom is increased appetite and weight loss, even though the patient eats a great deal. These symptoms result from too much of the hormone thyroxin in the blood.

One method of diagnosing this disorder is the BMR. An elevated BMR, the symptoms listed above and other characteristics of hyperthyroidism determined by clinical tests make diagnosis fairly easy.

Treatment consists of administering drugs which limit the production of excess thyroxin.

Approximately how much energy does the body obtain on the average from one gram of protein? From one gram of fat? From one gram of carbohydrate?

What are the two major processes included under the heading of metabolism?

What are some of the factors that affect the metabolic rate?

What is one medical condition that a BMR test is used to detect?

Vocabulary:

basal metabolic rate--the metabolic rate while at rest.

hyperthyroidism (HY-pur-THIGH-royd-izm)--a condition caused by excessive secretion of thyroxin by the thyroid gland.

metabolic rate (MET-uh-BAHL-ik)--the rate of energy expenditure by the body.

metabolism (meh-TAB-o-lizm)--the sum total of the chemical and physical processes in the cells by which large molecules are built from simpler ones and by which energy is released for use in the body.

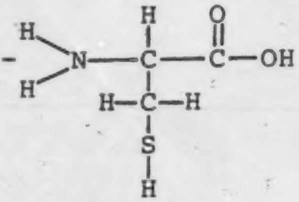
PROBLEM SET 24:

1. Determine the molecular weights of the following substances to the nearest amu. (Review Unit I, Section 26-1, if necessary.)

a. Propane--C_3H_8

b. Methylamine--CH_3NH_2

c. Cysteine--



2. The heat of reaction for the combustion of sucrose (table sugar) is -1350 kilocalories per mole.

$$C_{12}H_{22}O_{11} + 12\ O_2 \rightarrow 12\ CO_2 + 11\ H_2O + 1350\ \text{kcal}$$

a. Is the reaction exothermic or endothermic?

b. Find the molecular weight of sucrose.

c. Use the molecular weight to determine the energy content of one gram of sucrose. (Remember the equivalence of the physicist's kilocalorie and the nutritionist's calorie.) Is this value typical for carbohydrates?

SECTION 25: CELL RESPIRATION--AN INTRODUCTION

25-1 Respiration--a Metabolic Process

How do cells get energy from food?

As indicated in Unit I, there are two different ways to consider "respiration." We may view it as the processes involved in breathing gases in and out of the body as we did in Unit I. On the other hand, we may define respiration as those metabolic (chemical) processes involved in the production of energy from foods--more specifically, the breakdown of sugars and other nutrients to CO_2, water and energy.

The first definition was stressed in Unit I because our concern was with the respiratory system. In this unit, we will focus on the chemical changes that occur during the breakdown of nutrients, because this is essential to understanding the digestive system. However, the two views of respiration are not as different as they seem. We will find that the O_2 and CO_2 which we associate with breathing are very much involved in converting the potential chemical energy of nutrients to a form that is useful in the body.

There are good reasons to study the breakdown of various nutrients. Most important, these processes (1) link the digestive and respiratory systems, and (2) provide us with the energy needed for life. The study of cell respiration will lead to an understanding of how the chemical reactions of the body release energy and how these reactions convert energy to a useful form. The subject is of genuine medical significance. Diabetes, hyperthyroidism and other disorders are all related to cell respiration.

To illustrate the importance of cell respiration to medicine, we will consider a disorder characterized by diarrhea. The problem has been traced to milk and milk products and, as you might guess, it is of special importance in infants because of their diets. Analysis of the components of milk has revealed that the substance in milk that accounts for the gastrointestinal distress is lactose (milk sugar). The disease is known as "lactose intolerance" and occurs more frequently among some ethnic groups, such as black Americans, than among others.

In order to understand how undigested lactose can lead to gastrointestinal problems we need to consider how this sugar is digested. Lactose is a disaccharide that is hydrolyzed to the monosaccharides glucose and galactose in the small intestine.

$$\text{lactose} + H_2O \xrightarrow{\text{lactase}} \text{glucose} + \text{galactose}$$

Note that this metabolic step (i.e., reaction) is catalyzed by the enzyme lactase. Lactose itself cannot be absorbed into the body. But persons lacking this enzyme cannot break lactose down into monosaccharides. When dairy products such as milk are eaten by such persons, the undigested lactose serves as an extra food supply for intestinal bacteria, which convert the lactose to organic acids. The result is a large increase in the bacterial population, which in turn causes excessive reabsorption of water from the body into the intestinal tract. Thus the stools are watery and acidic and the individuals suffer from diarrhea. Once the condition is recognized as lactose intolerance, a low-lactose diet can be provided and the symptoms will disappear. Since lactose is found in milk, it is not easy to put infants on a low-lactose diet. It takes some planning for a dietician to provide a diet low in lactose and yet adequate in other nutrients.

25-2 A Metabolic Pathway

In what way is a metabolic pathway like a road map?

When biochemists discuss metabolism, they generally speak about metabolic pathways. A metabolic pathway is a series of reactions that a biochemical substance undergoes. For example, a nutrient Q might react to form a compound R which, in turn, might be converted to compound S and so on. Biochemists study these pathways to discover how they proceed and what they accomplish. Respiration (the production of energy from foods) is one of the most studied and most important pathways in metabolism.

"Reading" a metabolic pathway is like reading a road map. (See Figure 1, opposite.) A metabolic pathway takes us by chemical reactions from one chemical substance to another just as the map shows us how to get from one city to another. Some cities are centers from which one can choose any one of several routes. Likewise, some substances such as compound S are hubs of metabolism--they can be changed in different ways.

The metabolic pathway which we will consider is the breakdown of glucose to CO_2 and H_2O with the release of energy. But the metabolic process is not one step as suggested by Equation 1 below--it involves many steps.

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$$

And the energy derived from cell respiration is transferred to a compound abbreviated as ATP. The production of ATP is of major importance in cellular respiration.

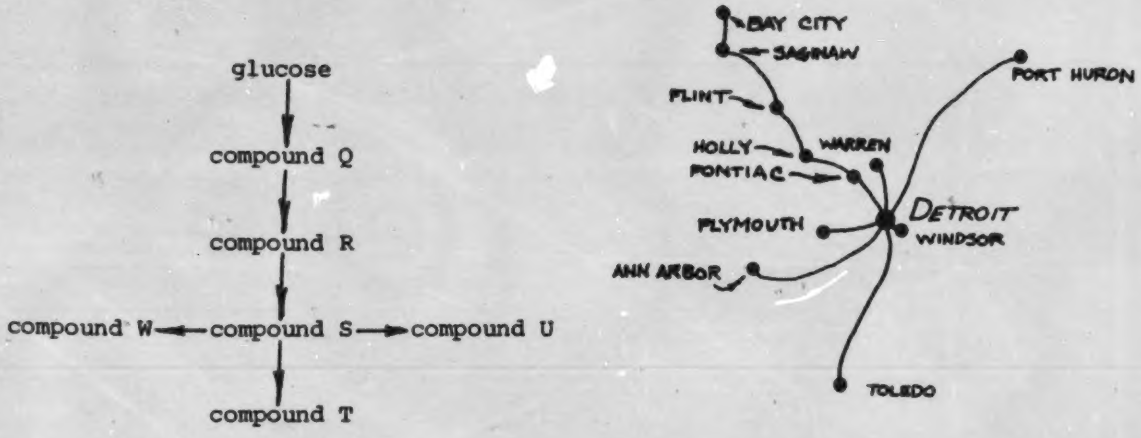
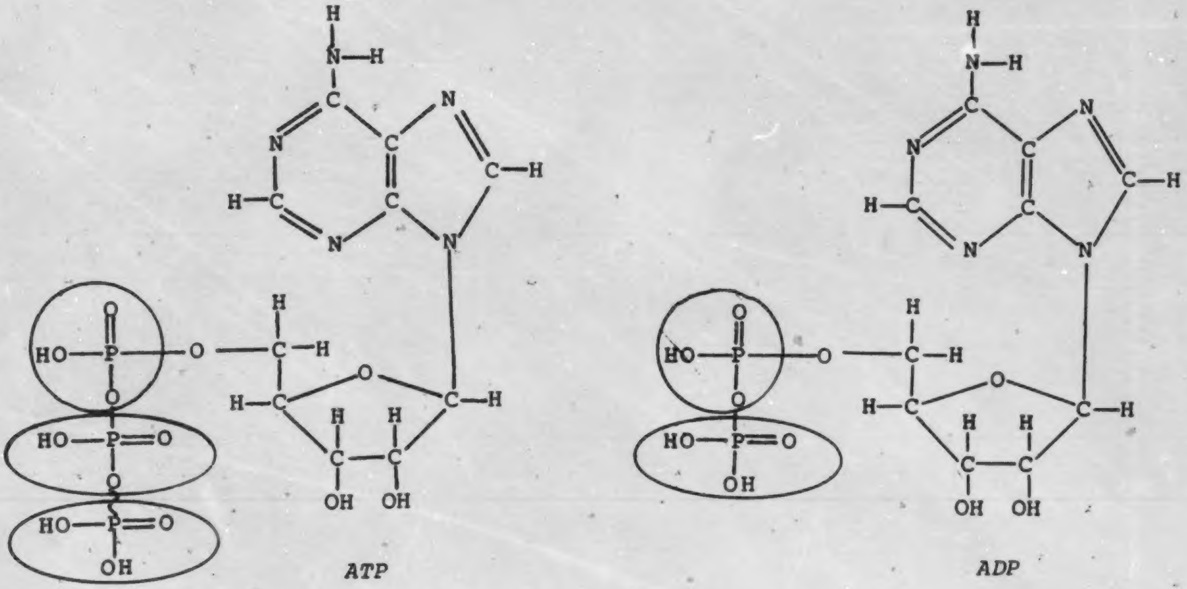


FIGURE 1: A. *Metabolic pathway.* B. *Road map, Detroit area.*

25-3 ATP--The Currency of Life

What is ATP? How does it work?

Ultimately every activity we perform--walking, digesting food, sleeping, etc., requires chemical energy contained in ATP molecules. Consider the structures of ATP and the related compound ADP. (See Figure 2.)



ATP *ADP*

FIGURE 1: *Structures of ATP and ADP.*

It is not necessary to memorize the structures of these complex molecules in order to understand how they function, but we do need to focus on the phosphate groups (circled). Note how nearly identical the two compounds are. They differ only by one phosphate group. ADP is adenosine diphosphate and "di" means two, while ATP is adenosine triphosphate and "tri" means three. It is this extra phosphate group in ATP that is central to the whole process of cell respiration. A squiggly line (∿) is shown between the second and third phosphate groups of the ATP. This symbol is used to mean that energy is released when the last phosphate group is broken off by hydrolysis (Equation 2).

$$\text{ATP} + H_2O \rightarrow \text{ADP} + \text{phosphate} + \text{energy} \qquad (2)$$

This energy is the "currency" we spend to perform many functions of life such as building proteins and contracting muscles.

The ATP currency is obtained from the reverse reaction (Equation 3).

$$\text{ADP} + \text{phosphate} + \text{energy} \rightarrow \text{ATP} + H_2O \qquad (3)$$

This reaction requires ADP, phosphate ions and energy. Phosphate is obtained from the diet and ADP is made from ingredients in the diet including amino acids.

The energy shown in Equation 3 comes from the metabolic breakdown of nutrients. That is why we said that the goal of cell respiration is the production of ATP.

25-4 Glycolysis--a Metabolic Process

What happens during the early stages of respiration?

The early stages of cell respiration involve a series of reactions in which glucose is quickly changed to a second compound (glucose phosphate), which in turn is rapidly converted to another compound and so on. In some of these reactions, small amounts of energy are released and transferred to ATP. One advantage to a process of energy release in small steps rather than one big one is that, if all of the energy of glucose or other nutrients were released at once, our cells might be damaged.

The early steps of cell respiration are known as glycolysis (literally "sugar splitting") and include all the steps in the conversion of glucose to a compound called pyruvic acid. The glycolysis pathway is shown in an abbreviated form in Figure 3, opposite. It is not essential to memorize the details of this shortened pathway. What is important to learn is how ATP is produced, for ATP is the energy currency of the body.

Figure 3 needs to be digested (excuse the pun) piece by piece--it contains a lot of information. Begin with glucose. According to the figure, glucose is converted to another 6-carbon compound which is converted to still another 6-carbon compound. In the next step, that 6-carbon compound is split into two halves and the

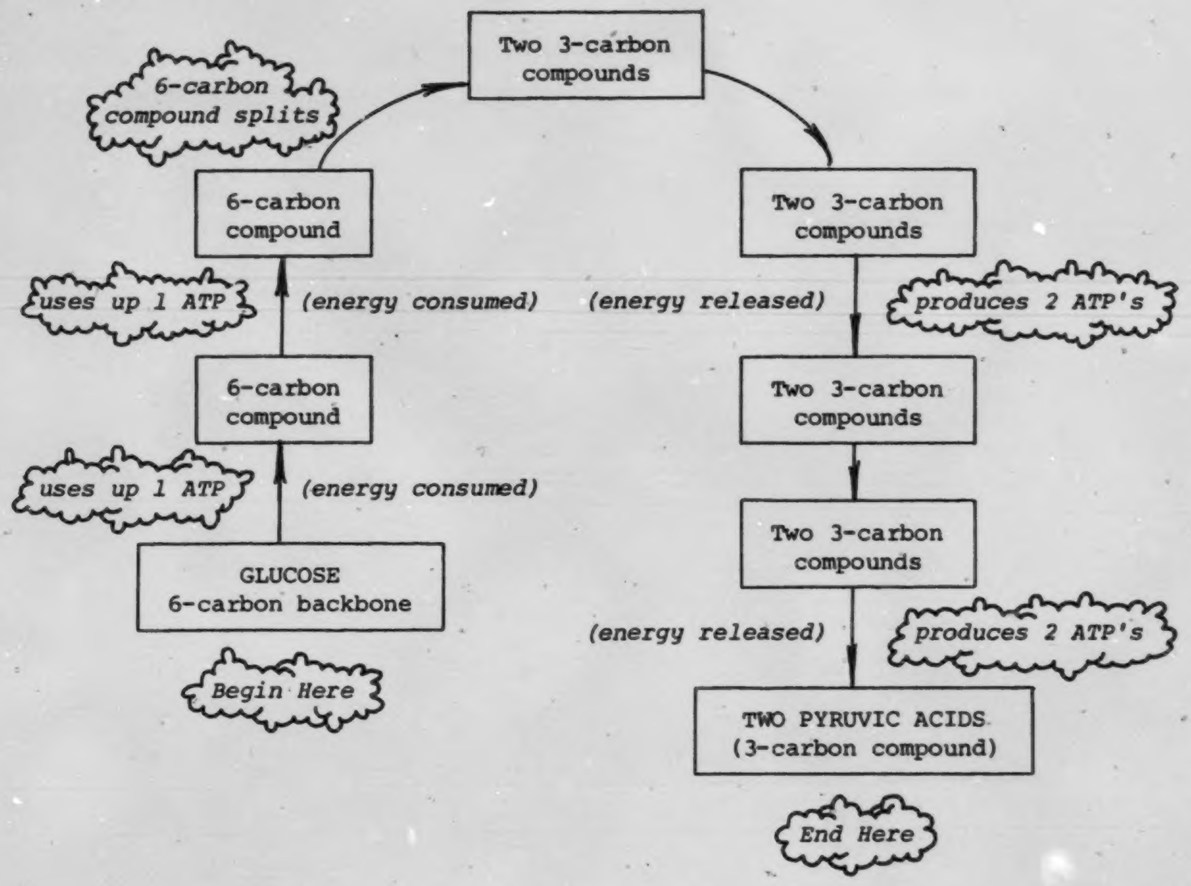


FIGURE 3: *Metabolism of glucose--glycolysis.*

3-carbon products are converted step-by-step to pyruvic acid. So much for the metabolic pathway. Of more importance is the relationship of glycolysis to ATP production. Figure 3 shows that in the very first step, ATP is used up. This is a simple way of stating that the change in glucose is accompanied by the hydrolysis of ATP to ADP (Equation 2). Now, you might raise an objection here--we seem to be losing an ATP in this step, and the function of this process is to gain ATP's in cell respiration. If you raised this objection, you made a good point. But it is necessary to consider the entire glycolysis scheme to determine whether there is an overall gain of ATP. Review the entire pathway in Figure 3 and see if you can convince yourself that there is a net gain of 2 ATP's. Glycolysis may be summarized in a single equation.

$$\text{glucose} + 2\ \text{ADP} + 2\ \text{phosphate} \rightarrow 2\ \text{pyruvic acid} + 2\ \text{ATP} \qquad (4)$$

25-5 The Rest of Cell Respiration

How do we gain additional ATP in cell respiration?

Equation 4 indicates that glucose (a 6-carbon compound) is converted to pyruvic acid (a 3-carbon compound). Yet in Section 25-2 and elsewhere we have stated that in cell respiration, the breakdown of glucose yields CO_2 (Equation 1). How can we reconcile these two different statements?

In further stages of cell respiration the pyruvic acid formed produces more ATP. The metabolic process is complex, but the details are not critical to the story. We can outline the results (which are critical to the story) very briefly.

1. Each pyruvic acid molecule also forms 3 CO_2 molecules. (This is occurring in enormous numbers of cells and explains the CO_2 formed as an end-product from glucose and why we exhale more CO_2 than we inhale.)

$$\underset{\text{(3-carbon compound)}}{\text{pyruvic acid}} \rightarrow \text{2-carbon compound} + CO_2 + \boxed{\text{energy}}$$

$$\text{2-carbon compound} \rightarrow 2\ CO_2 + \boxed{\text{energy}}$$

2. During cell respiration, chemical energy is transferred to a variety of compounds some of which are new to this discussion. Two of these compounds provide energy directly for production of ATP but only if oxygen is present. Actually much of the ATP produced in cell respiration is obtained in this way. (This explains why oxygen is needed in cell respiration and why we have to inhale oxygen to survive.) This process is explained schematically

$$\begin{tikzcd}[column sep=small] \text{compound} + O_2 \rightarrow \text{new compound} + H_2O + & \boxed{\text{energy}} \arrow[d, dash] & \\ \text{ADP} + \text{phosphate} + & \boxed{\text{energy}} & \rightarrow \text{ATP} + H_2O \end{tikzcd}$$

3. As a result of the complete oxidation of a mole of glucose to CO_2 and H_2O, 36 moles of ATP are obtained. Each mole of ATP accounts for about 10 Cal (nutritionist's calories), so the total energy in all the ATP produced is

$$36 \text{ moles ATP} \times 10\ \frac{\text{Cal}}{\text{mole ATP}} = 360 \text{ Cal}$$

However, if a mole of glucose is burned in a calorimeter, 673 Cal can be released as heat. So only about half of this energy can be accounted for by the ATP. Does this mean that the Law of Conservation of Energy is broken by living organisms? The answer is a resounding "NO." In cell respiration, some of the chemical energy of glucose is converted to heat and this heat energy keeps us warm. During most of our lives our internal temperature must be kept higher than the temperature of the environment.

In this section we have introduced some complex metabolic pathways. They are crucial because all life and all the processes of life require energy. In fact, one of the chief functions of food is to provide energy. We have seen how glucose, a carbohydrate, is broken down to smaller pieces through a series of metabolic steps. In this process energy is transferred from the glucose molecules to ATP molecules. The ATP molecules can be hydrolyzed as needed by the body to perform various functions. For example, hydrolysis of ATP can provide the energy needed for synthesis of proteins. Also, hydrolysis can supply the energy needed to reorganize the proteins in muscle tissue causing a muscle to contract. In the next section we will consider how other nutrients and enzymes fit into cellular respiration.

What are two ways to define "respiration?"

How is a metabolic pathway analogous to a road map?

What is the main chemical form in which the energy in glucose is captured during cellular respiration?

What is accomplished by glycolysis? By cell respiration?

How do ADP and ATP differ? How is this difference related to the importance of ATP?

What is an advantage of a step-by-step breakdown of glucose?

Explain how energy is conserved in cell respiration.

Vocabulary:

adenosine diphosphate (ah-DEN-o-seen)--ADP, a substance that may be converted to adenosine triphosphate (ATP), thereby storing chemical energy.

adenosine triphosphate--ATP, a compound that releases energy for biological processes; the "energy currency" of life.

glycolysis (gly-COL-uh-sis)--the breakdown of glucose to pyruvic acid with release of energy.

metabolic pathway--a series of related chemical reactions that occur in living organisms.

SECTION 26: FACTORS RELATED TO CELL RESPIRATION

26-1 The Metabolism of Fats and Proteins

How do fats and proteins fit into the scheme of cell respiration?

In Section 25, the metabolic breakdown of glucose was described and the relation of this process to energy production within cells was stressed. But there is more to metabolism than metabolic steps. In this section we will consider the stage on which metabolism occurs and some of the performers not yet discussed. The stage is the cell; almost any kind of cell will do. The performers include enzymes and other nutrients besides sugars (Figure 1).

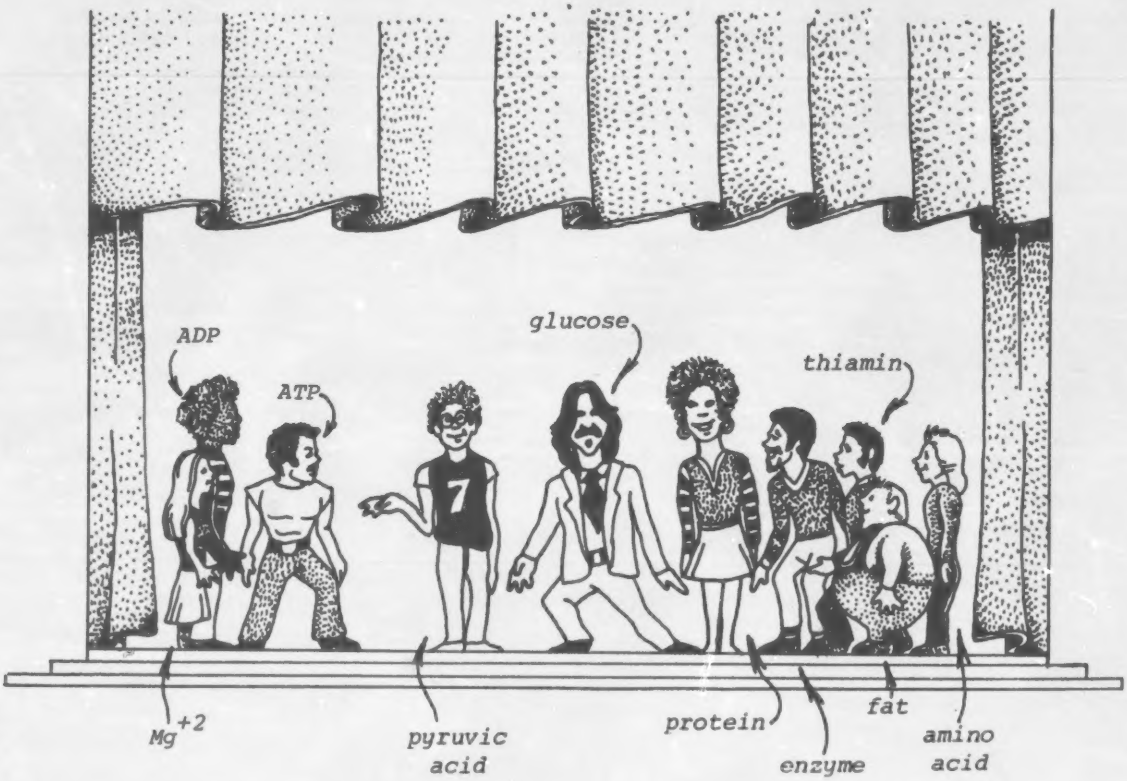


FIGURE 1: *Some of the performers in the metabolic drama.*

In earlier sections as well as in Biomedical Mathematics, it has been stressed that not only carbohydrates, but also fats and proteins are energy sources. So far we have shown only how glucose can release energy to make ATP. The relationship of glucose to ATP is depicted in Figure 2, opposite. The pathways of metabolism that have been discussed so far are shown within the rectangle. But, cell respiration is by no means limited to glucose as a source of energy for the production of ATP. The relationship of other cellular nutrients to ATP is also shown in Figure 2 (outside the rectangle). Various carbohydrates in the cell can be converted to glucose and then broken down to release energy by the metabolic processes we have been discussing.

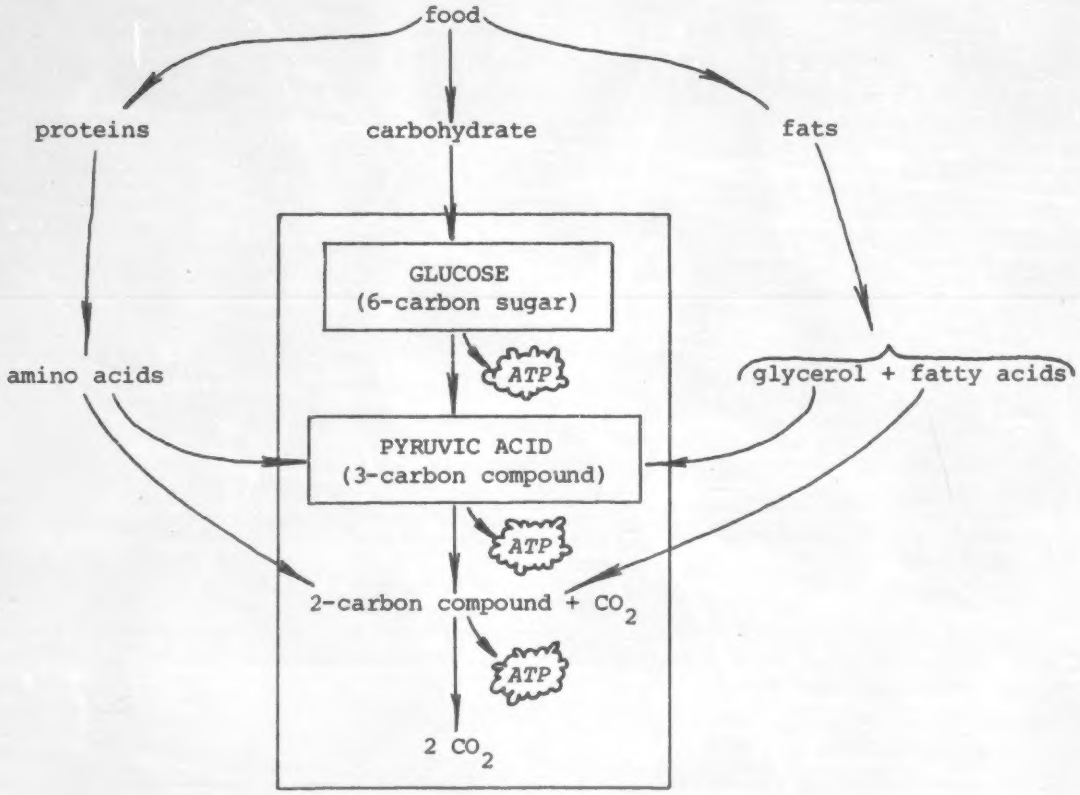


FIGURE 2: *Cell respiration.*

Fats can also be oxidized by the cell for ATP production. In fact this is the objective of dieters trying to lose weight. By oxidizing fat from storage tissues throughout the body excess weight is lost. Fats enter the metabolic pathways at two different stages of respiration as indicated in the figure. In the cell, fats are broken down into glycerol and fatty acids. The glycerol is converted to a 3-carbon compound that is converted to pyruvic acid. The fatty acids form 2-carbon compounds which can be broken down providing the energy needed to form ATP. Proteins within the cell can also be used as an energy source. When this happens, the amino acids produced by hydrolysis of proteins fit into the metabolic scheme as shown in Figure 2.

26-2 Enzymes, Genes and Metabolism

How are enzymes and genes related to cell respiration?

If you were to set a cube of sugar on a table and expose the sugar to oxygen (air), you would have to wait a long time, perhaps centuries, for the sugar to be changed to CO_2 and H_2O. Even if you dissolved the sugar in water, glycolysis would still proceed very slowly as long as bacteria were kept out of the solution. If some bacteria happened to land in the sugar solution, the breakdown of sugar would be much more rapid. This is because the bacteria would introduce enzymes into the solution. For each metabolic step in respiration, a specific enzyme is needed. Without these enzymes, the reactions of metabolism would proceed far too slowly to maintain life.

There is an important relation between enzymes and inheritance. Just as we inherit eye color and hair form (i.e., curly or wavy or straight hair) from our parents, we are born with the capacity to synthesize a vast number of different kinds of enzymes. You may already be aware that the units of inheritance are called genes. You will study genes in a later unit, but at this stage, it is important to note that there is a specific gene that controls the production of each enzyme.

The importance of the gene-enzyme relationship becomes evident in metabolic disorders such as cretinism. In the past, people born with this disease were mentally and physically retarded. In addition, they developed a form of goiter, a disease mentioned in Section 19. The presence of goiter provides the clue that cretinism has something to do with an iodine deficiency. In fact, people affected with cretinism have goiters because they cannot produce thyroxin, a hormone that contains iodine atoms. The cannot produce this substance because they lack a particular enzyme which catalyzes the synthesis of thyroxin. And they cannot make this enzyme because they are born without a specific gene (Figure 3).

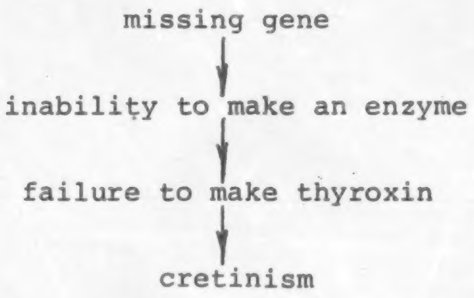


FIGURE 3: *Relationship of a gene, an enzyme and a metabolic disorder.*

Now, as a result of studies in genetics and biochemistry, individuals with cretinism can be detected early and provided with thyroid hormones which permit them to grow and develop normally.

26-3 The Link Between Vitamins and Metabolism

What do vitamins have to do with cell respiration?

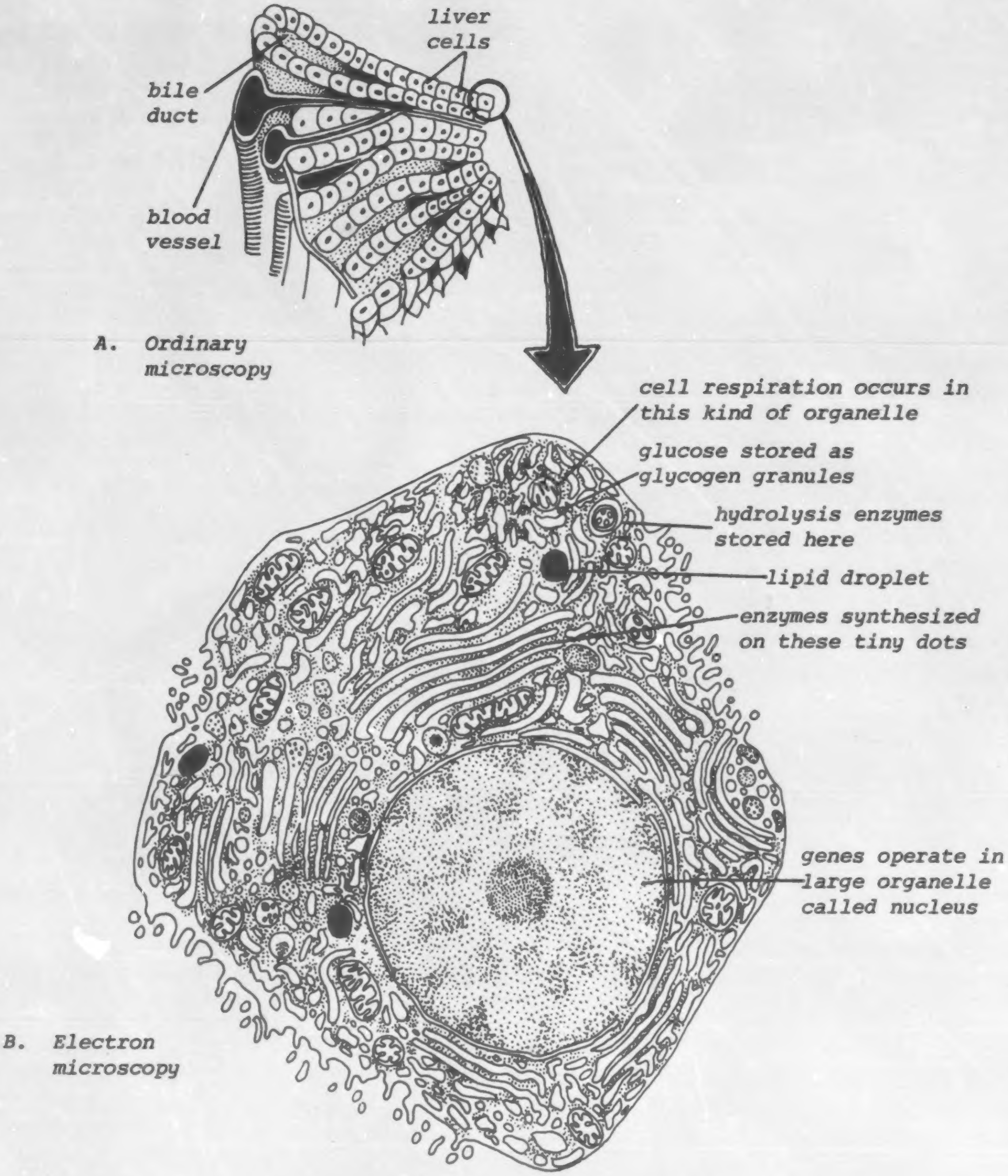
For many years it has been known that vitamin deficiencies can lead to diseases such as beriberi and scurvy. But biochemists have not been satisfied with this level of explanation of why vitamins are important. They wanted to know how vitamins function in the body. As a result of biochemical research, several vitamins have recently been found to have a direct relation to cell respiration. Let's take one specific example. In Section 25, we pointed out that the pyruvic acid formed in glycolysis can be further broken down to release energy. In the first step of the breakdown of pyruvic acid, a two-carbon compound is formed (Figure 2). For this step to occur, not only is an enzyme needed, but also four other substances--thiamin, niacin, lipoic acid, pantothenic acid. Each of these substances is a B-complex vitamin. These compounds help an enzyme to catalyze a metabolic step. Other vitamins are also required in cell respiration.

26-4 Cell Structure and Metabolism

How is the internal structure of the cell adapted for cell respiration?

At this point in our explanation we have discussed numerous molecules and enzymes. But an annoying question remains. How do all of these different molecules and enzymes react properly?

The answer to this question was not apparent to scientists until the electron microscope was applied to the study of cells. Figure 4, on the following page, compares the appearance of liver cells as seen with an ordinary microscope and with an electron microscope. The electron microscope reveals a whole new world within a cell. Inside a cell, there are many compartments and tiny structures of different shapes called organelles (literally small organs). Organelles are specialized, performing particular functions. Highly organized structures like these help to ensure rapid metabolism. Some of these structures are indicated in Figure 4B. Chemicals being metabolized are moved from one organelle to another. When needed, the enzymes made in one part of the cell move to the organelle where cell respiration occurs. After ATP is produced, it is released for use within the cell. By organizing the tasks of metabolism, the process becomes more efficient. The microscopic structure of the cell is seen to be a valuable adaptation.


liver cells
bile duct
blood vessel
cell respiration occurs in this kind of organelle
glucose stored as glycogen granules
hydrolysis enzymes stored here
lipid droplet
enzymes synthesized on these tiny dots
genes operate in large organelle called nucleus

A. *Ordinary microscopy*

B. *Electron microscopy*

FIGURE 4: *Liver cells.*

How can fats and proteins be used as energy sources?

Why are enzymes needed for metabolic pathways?

How are genes involved in metabolism?

What are some other substances required for cell respiration besides genes, enzymes, fats and proteins. What do they do?

What does the electron microscope reveal about the nature of a cell?

How do organelles contribute to efficiency in metabolic processes?

Vocabulary:

cretinism (KREE-tin-izm)--an inherited condition characterized by mental and physical retardation when untreated.

gene--the unit of inheritance.

organelle (OR-guh-NEL)--a structure within a cell that performs one or more specific functions.

SECTION 27: CHEMICAL EQUILIBRIUM

27-1 What is Meant by an Equilibrium?

In Sections 25 and 26, we have seen that several of the nutrients in food are broken down through metabolic pathways (cellular respiration). The most important points stressed were that (A) energy is released from nutrients by chemical reactions, (B) some of this energy is transferred to ATP and (C) ATP may be viewed as the currency of life because when it is converted back to ADP, energy is released for biological processes. This is all summarized in Figure 1, on the following page.

Figure 1 indicates the importance of ATP. ATP may also seem a little mysterious because we have not yet explained how the energy in ATP is used by the body. First we need to consider a basic physical principle called equilibrium.

One example of equilibrium is the state of an object that is motionless, such as a sack of potatoes resting on the kitchen floor. This is an example of static equilibrium.

Chemical equilibirum, however, is different. It occurs when two opposite reactions are taking place at the same rate. The effect of one reaction balances the effect of the opposite reaction. (The term "equilibrium" comes from the Latin words "equi" meaning "equal" and "libra" meaning "balance.") Such a process is a dynamic one, and the net effect is a dynamic equilibrium.

(A) compound X $\rightarrow$ compound Y + energy

(B) ADP + phosphate + energy $\rightarrow$ ATP + H_2O

(C) ATP =

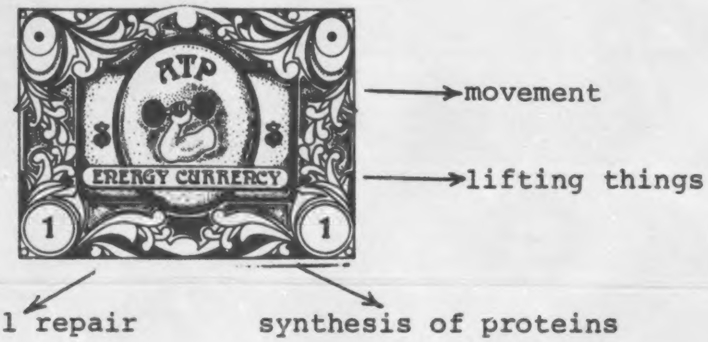
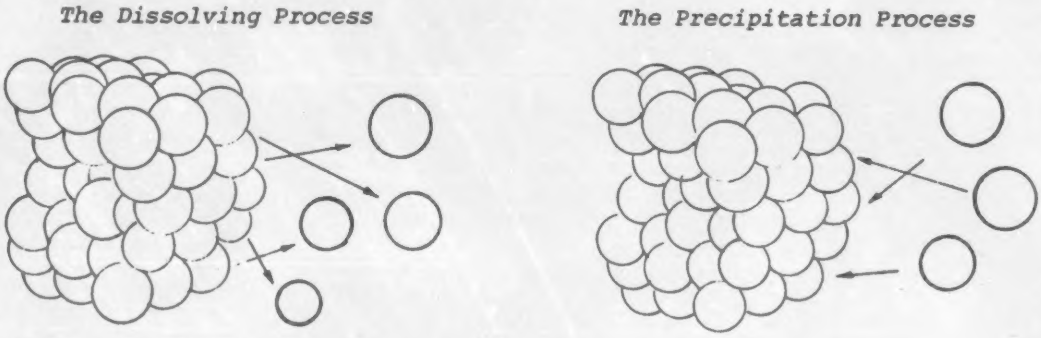


FIGURE 1: *Some key points of Sections 25 and 26.*

For example, consider a beaker containing a saturated solution of $CaSO_4$ (calcium sulfate--better known as "plaster of Paris"). A saturated solution is one in which the solvent (water) contains as much of the dissolved solute (calcium sulfate) as it can hold. If there is excess calcium sulfate, it will precipitate out of solution. But chemical changes are still going on. Some of the molecules of $CaSO_4$ are dissolving into the solution; some of the molecules in the solution are precipitating out (Figure 2).


The Dissolving Process

The Precipitation Process

FIGURE 2: *Two simultaneous processes in a saturated solution.*

When these two effects exactly counteract each other--that is, when they occur at the same rate--then we have equilibrium. The processes (dissolving, precipitation) are balanced. The solution remains saturated, and there is no net change in the concentration of the solution.

Another example of this kind of equilibrium is shown in Figure 3. Here, we have a box containing a partition with a hole in it. Gas molecules are zipping about in random motion on both sides of the partition.

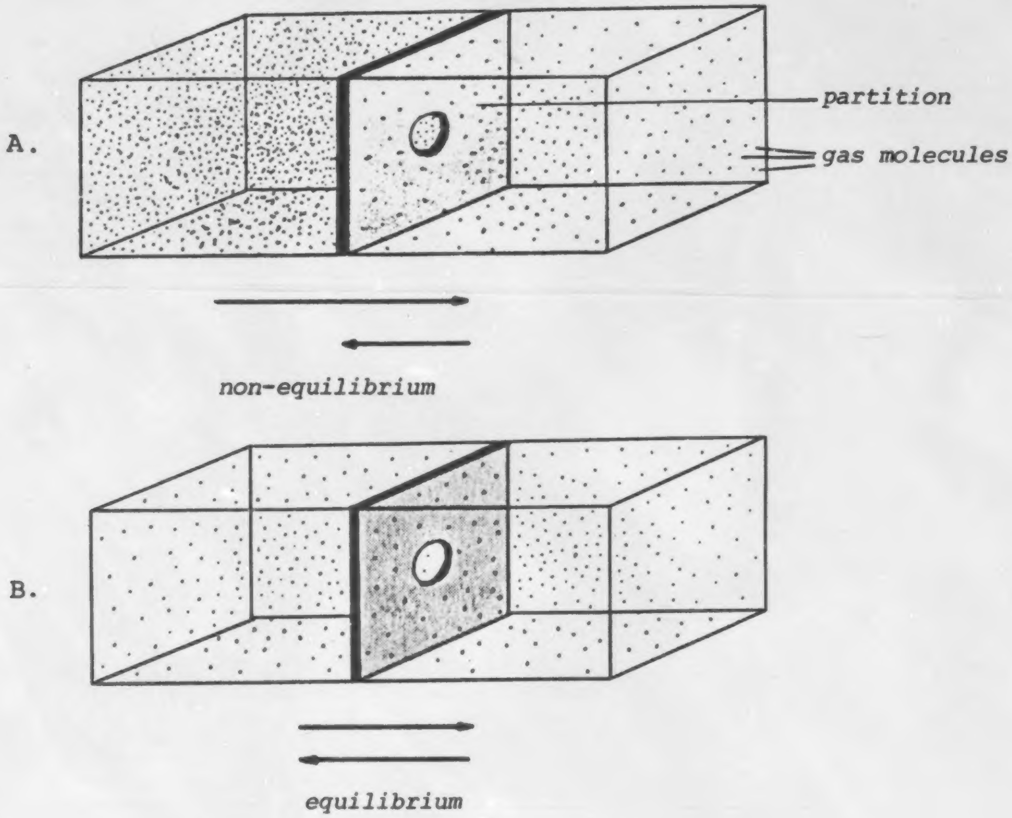


FIGURE 3

A. *A non-equilibrium situation.*

B. *An equilibrium situation.*

In Figure 3A, there are more gas molecules on the left side of the partition than on the right. Therefore, more molecules will move at random through the hole from left to right than in the opposite direction. This is a non-equilibrium condition, which we symbolize with the unequal arrows below the box.

The molecules will continue this unequal flow until there are as many on the right side of the partition as on the left (Figure 3B).

Now we have equilibrium, as symbolized by the equal arrows below the box. The molecules have not stopped flowing between the two sides of the box, but they are flowing at the same rate in each direction--in other words, the equilibrium is dynamic.

27-2 Reversible Reactions and the Position of an Equilibrium

What is happening at equilibrium in a reversible reaction?

You may recall that many chemical reactions may go in either direction--they are reversible. Consider the following reaction.

$$\underset{\text{carbon dioxide}}{CO_2} + H_2O \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3}$$

Note that the arrows point in both directions as in Figure 3. In both cases, we can describe the processes in terms of an equilibrium. If we mix CO_2 and H_2O, H_2CO_3 will form. As product molecules form, some of the H_2CO_3 molecules will break down to form CO_2 and H_2O. Eventually the H_2CO_3 will dissociate to CO_2 and H_2O at the same rate as the two reactants come together to form H_2CO_3. When this happens, we have a dynamic equilibrium. HOWEVER, THIS DOES NOT MEAN THAT AT EQUILIBRIUM THERE WILL BE AN EQUAL NUMBER OF REACTANT AND PRODUCT MOLECULES. At equilibrium, we could have many more reactant molecules than product molecules or vice versa.

The reactions that we have been considering in the Nutrition Unit are reversible. Some examples of familiar reversible reactions are shown in the table below.

	REACTION	AT EQUILIBRIUM, Mostly
1*	ATP + $H_2O \rightleftharpoons$ ADP + phosphate	products
2*	ADP + phosphate $\rightleftharpoons$ ATP + H_2O	reactants
3	lactose + $H_2O \rightleftharpoons$ glucose + galactose	products
4	starch + $H_2O \rightleftharpoons$ glucose	products
5	fats + $H_2O \rightleftharpoons$ fatty acids + glycerol	products
6	amino $acid_1$ + amino $acid_2 \rightleftharpoons$ peptide + H_2O	reactants
7	glucose + fructose $\rightleftharpoons$ sucrose + H_2O	reactants

*Reactions 1 and 2 show two ways to represent the same reaction.

Note that in some equilibria there are mostly products, while in others there are mostly reactants. Careful study of the table suggests a useful generalization: hydrolysis reactions favor the products while dehydration synthesis favors the reactants. The proportion of products to reactants determines the "position" of an equilibrium. The position of equilibria in the chemical reactions of the cell is of more than passing interest. Dehydration synthesis reactions such as production of peptides, proteins and glycogen are key reactions in life. Our cells are constantly making these compounds. How then can we survive when such reactions form very little product?

Enzymes are not the solution to this problem. Although enzymes and other catalysts may speed a reaction greatly, catalyzed reactions can go no further than the equilibrium position. (This is because the enzyme increases the speed of reactions in both directions.)

The problem of unfavorable equilibrium positions is solved in the cell by shifting the position of the equilibrium. How this is accomplished is the subject of Section 28. It may not surprise you to learn that ATP is involved in determining the positions of many important equilibria.

Give some examples of equilibria. Are they "static" or "dynamic?"

Describe what is happening to the molecules when a chemical reaction has reached equilibrium.

Write the equation for the hydrolysis of ATP. Compare the situation as the reaction begins and at equilibrium. Does the equilibrium favor the reactants or products? Can the equilibrium position be shifted by the presence of an enzyme?

Vocabulary:

chemical equilibrium--the situation in which the forward and reverse processes of a chemical reaction are occurring at equal rates (i.e., when reactants are changing to products as rapidly as the products are changing back to reactants).

dynamic equilibrium--an equilibrium in which opposing processes have equal but opposite effects, so that overall there is no net change.

precipitate (pre-SIP-ih-tate)--to come out of solution as a solid.

saturated (SATCH-uh-RAY-tid)--said of a solution in which the solvent contains as much dissolved solute as it can hold.

static equilibrium--an equilibrium in which no changes are occurring.

SECTION 28: SHIFTING THE POSITION OF AN EQUILIBRIUM

28-1 ATP, Energy and the Position of an Equilibrium

How does ATP increase the quantity of products of a reaction?

In Section 27 we pointed out that in many processes, such as the formation of peptides from amino acids, very little product should be expected at equilibrium.

$$\text{amino acid}_1 + \text{amino acid}_2 \rightleftharpoons \text{peptide} + H_2O$$

Likewise in some of the reactions of cell respiration, the equilibria favor the reactants. These situations suggest a real challenge to survival--for if amino acids did not readily form peptides, we would not be able to make sufficient proteins to survive. In order for peptides and proteins to be made in sufficient quantity, the position of equilibrium has to be shifted to increase the proportion of products to reactants.

To understand how an equilibrium is shifted, we need to know what determines the position of an equilibrium. The determining factor turns out to be something we have been discussing--energy. The energy to which we are referring is related to ΔH_r, the heat of reaction. In general, exothermic reactions tend to favor the products while endothermic reactions tend to favor the reactants. ATP hydrolysis is exothermic so, at equilibrium, there is mostly product and little remaining ATP. (See Figure 1.)

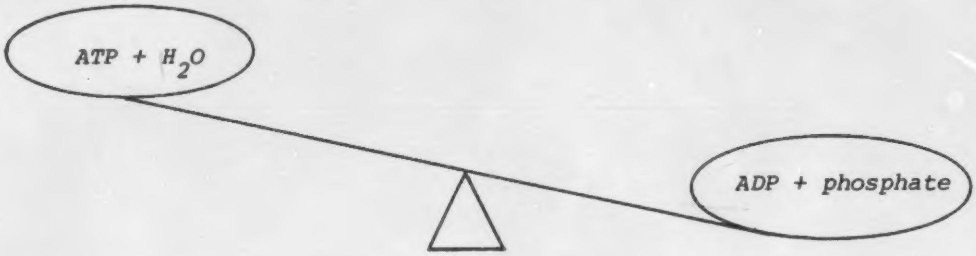


FIGURE 1: *Equilibrium favoring products.*

$$ATP + H_2O \rightleftharpoons ADP + \text{phosphate} + \text{energy}$$

On the other hand, dehydration synthesis of a peptide from two amino acids (aa_1 and aa_2) is endothermic and the equilibrium favors the reactants. (See Figure 2 on the following page.)

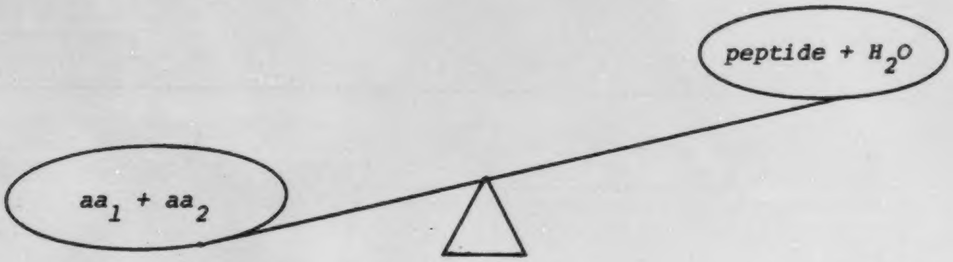


FIGURE 2: *Equilibrium favoring reactants.*

$$\text{energy} + aa_1 + aa_2 \rightleftharpoons \text{peptide} + H_2O$$

The reverse of any endothermic reaction is an exothermic reaction. For example, the hydrolysis of a peptide to produce amino acids is exothermic. Thus the general tendency may also be stated that a reaction tends to proceed in the direction in which energy is released.

The dehydration synthesis of peptides from amino acids is endothermic and would not produce much product if this reaction could not be combined with an exothermic reaction. The exothermic reaction is the hydrolysis of ATP.

In the presence of the proper enzymes, ATP reacts with one of the amino acids to form an intermediate compound; this compound then reacts with the other amino acid to form a peptide, while the ATP is converted to ADP. The net result of these reactions is

$$\text{amino acid}_1 + \text{amino acid}_2 + \text{ATP} \rightleftharpoons \text{peptide} + \text{ADP} + \text{phosphate}$$

The overall reaction is exothermic, so equilibrium is shifted toward the products (Figure 3).

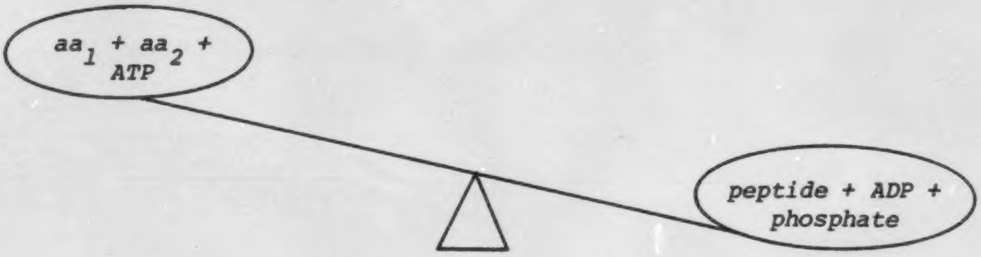


FIGURE 3: *Equilibrium shifted to favor products.*

ATP plays a similar role in facilitating many endothermic biological processes. In addition, the body has other ways to shift an equilibrium.

28-2 Le Chatelier's Principle

What devices other than ATP are used by the body to facilitate endothermic reactions?

Cellular respiration, as we saw, involves a sequence of reactions.

$$\text{glucose} \rightleftharpoons \text{compound Q}$$

$$\text{compound Q} \rightleftharpoons \text{compound R}$$

$$\text{compound R} \rightleftharpoons \text{compound S}$$

$$\text{compound S} \rightleftharpoons \text{pyruvic acid}$$

If one of these reactions formed little product, it would interfere with the release of energy from foods. For example, suppose that the conversion of compound Q to compound R has an equilibrium favoring the reactant. In this case, very little compound R would form and, in turn, very little compound S and pyruvic acid would be made. This result would be disastrous--it would mean that very little of the energy of nutrients could be made available to us.

Fortunately, however, what would appear to be a bottleneck, such as an unfavorable equilibrium between Q and R, does not prevent cells from obtaining energy from glucose. The reason involves a principle first stated by Le Chatelier, a French scientist, in 1888. According to Le Chatelier's principle, if a change is made in some variable that affects a reaction, the reaction will shift in such a way as to tend to compensate for the change. In other words, changing the concentration of a reactant or a product upsets the equilibrium--a reaction occurs until equilibrium is again attained. For example, if more reactants are added, then the reaction will shift to decrease the amount of reactants by producing more products. Similarly, if a product is removed from a reaction, then the reaction will shift so that more product will be formed.

When compound Q forms compound R during cell respiration, most of compound R immediately reacts to form compound S. That is, R is continually being removed. At equilibrium, there is a certain proportion of R to Q. As long as R is removed, Q continues to react in an effort to establish equilibrium. As a result essentially all Q reacts. Thus a reaction with an unfavorable equilibrium does not hinder the process of cell respiration.

How does Le Chatelier's principle apply to actual reactions in the cell? In one of the first reactions of glycolysis, glucose phosphate is changed to fructose phosphate. If this reaction occurred in a test tube, very little fructose phosphate would form.

$$\text{glucose phosphate} \rightleftharpoons \text{fructose phosphate}$$

Consequently, you might expect that this reaction would limit cell respiration. However, in the body the fructose phosphate that forms is quickly converted to another compound in another metabolic reaction. In other words, the fructose phosphate is removed. So glucose phosphate continues to make more fructose phosphate in an effort to reestablish equilibrium. The more fructose phosphate made, the more is removed through metabolism. Thus this reaction never becomes the stumbling block in cell respiration that we might have predicted. This is a very common device for shifting equilibria in metabolism.

As another example of the application of Le Chatelier's principle to chemical equilibrium, recall that beverages are carbonated by the reversible reaction

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

The beverage is bottled with a high partial pressure of CO_2, which is in equilibrium with the H_2CO_3 in the beverage. When the bottle is opened, CO_2 escapes into the air. The partial pressure of CO_2 thus decreases; to reestablish equilibrium, more H_2CO_3 dissociates to H_2O and CO_2. Eventually equilibrium is reached again, but less H_2CO_3 remains in the liquid.

Chemists have investigated equilibria for over 100 years. They have discovered several ways to shift an equilibrium so that they can obtain more products. The "devices" used involve manipulations of pressure, temperature and the concentrations of the molecules participating in a reaction. The human being is not adapted to change internal pressure or temperature significantly--in fact, we are very limited in the range of such changes we can tolerate. Instead, our technique to improve the yield of a reaction is generally to modify the concentrations of the products (or to add ATP, as discussed above).

28-3 How Can We Describe the Position of an Equilibrium?

It is helpful to have a numerical way to describe the equilibrium position. For reactions in which the balanced equation shows only one molecule of each reactant and product, chemists have shown that at any given temperature at equilibrium, the product of the concentrations of the substances formed in a reaction, divided by the product of the concentrations of the reactants, is a constant, K_{eq}. For example, for any reaction of the type: $A + B \rightleftharpoons C + D$,

$$K_{eq} = \frac{[C][D]}{[A][B]}$$ [ ] means concentration in moles per liter.

If a substance A, is converted to a substance B, such as the conversion of glucose phosphate to fructose phosphate, the equation is simply $A \rightleftharpoons B$

$$K_{eq} = \frac{[B]}{[A]}$$

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The use of the equilibrium constant, K_{eq}, will become more apparent if we apply it to a few metabolic reactions.

EXAMPLE 1:

In one of the reactions of glycolysis, glucose phosphate is converted to fructose phosphate. At equilibrium, the ratio of the concentration of glucose phosphate to that of fructose phosphate is 7:3. What is K_{eq}?

SOLUTION:

$$\text{glucose phosphate} \rightarrow \text{fructose phosphate}$$

$$K_{eq} = \frac{[\text{fructose phosphate}]}{[\text{glucose phosphate}]} = \frac{3}{7} \simeq 0.43$$

Reactions like this one in which $K_{eq} < 1$ tend to be endothermic ones. The equilibrium constant is thus another way of expressing the extent to which a reaction takes place. A $K_{eq} > 1$ indicates that the equilibrium tends to favor the products; a $K_{eq} < 1$ indicates an equilibrium favoring the reactants.

EXAMPLE 2:

Consider a strongly exothermic reaction such as ATP hydrolysis (Figure 1). What kind of value of K_{eq} might we find?

SOLUTION:

In contrast with endothermic reactions such as Example 1, an exothermic reaction generally has a $K_{eq} > 1$. (In fact, K_{eq} for ATP hydrolysis is a staggering 800,000. At equilibrium, the molecules present are almost exclusively products.)

Why is it important that the body have mechanisms to shift equilibria?

What determines the extent to which a reaction takes place?

If a reaction is endothermic, would you expect to find mostly reactants or mostly products at equilibrium?

How does ATP change the position of an equilibrium?

What are some ways that the products formed in a reaction can be increased? Which of these methods is used by the body?

How does Le Chatelier's principle apply to cell respiration?

What are two ways in which a product can be removed from a reaction?

Suppose K_{eq} for a reaction is 63. What can be concluded about the equilibrium position? Would this reaction be exothermic or endothermic?

Vocabulary:

equilibrium constant--K_{eq}; the product of the concentrations of the substances formed in a reaction divided by the product of the concentrations of the reactants. (For reactions in which the balanced equation shows more than one molecule of any reactant or product, the definition is more complex.)

Le Chatelier's principle (luh-SHAT-tull-YAYS)--if a change is made in some variable that affects a reaction, the reaction will shift in such a way as to tend to compensate for that change.

PROBLEM SET 28:

1. For the conversion of pyruvic acid to a two-carbon compound, the equilibrium constant is > 1.

a. Is the reaction likely to be exothermic or endothermic?

b. Is ΔH_r a negative or positive number? (Recall that if energy is released, ΔH_r is negative.)

For each of the next two problems, indicate

a. whether the reaction in the forward direction is exothermic or endothermic.

b. whether the reaction in the reverse direction is exothermic or endothermic.

c. whether ΔH_r for the reaction in each direction is positive, negative or zero.

2. $$\underset{\text{(amino acid)}}{\text{glycine}} + \underset{\text{(amino acid)}}{\text{alanine}} \rightleftharpoons \underset{\text{(peptide)}}{\text{glycylalanine}} + H_2O$$

3. $\text{ATP} + H_2O \rightleftharpoons \text{ADP} + \text{phosphate}$

4. Assume that A and B are reacting to form C and D, and that the equilibrium concentrations are 8 moles of C, 8 moles of D and 1 mole each of A and B. What is K_{eq}? (Hint: If necessary, review the definition of equilibirum constant.)

5. Assume that in the conversion of lactose (milk sugar) to glucose and galactose the equilibrium proportions are 1 mole of lactose to 1 mole of H_2O to 12 moles of glucose to 12 moles of galactose. What is K_{eq}?

$$\text{lactose} + H_2O \rightarrow \text{glucose} + \text{galactose}$$

SECTION 30: DIET AND IDEAL WEIGHT

30-1 Dietary Needs

Are dietary needs the same for everyone?

You have used Activity 29 to calculate the quantities of several nutrients in your diet for one day. In this and the following section we will review the various nutrients and give you a basis for deciding how much of each nutrient your diet should include.

Dietary needs are commonly expressed in terms of "Recommended Daily Allowances." Recommended Daily Allowances (abbreviated RDA) have been established for most nutrients by the Food and Nutrition Board of the National Academy of Sciences. The Recommended Daily Allowances are those quantities that the Board believes are necessary for good nutrition in almost all healthy people. The allowances are given in terms of quantities per day.

Note that the allowances are meant to be sufficient for most people. There is great variation among individuals, and the recommendations include an allowance for these variations. The recommendations are not adequate, however, for individuals with certain medical problems.

Recommended Daily Allowances are not the same as Minimum Daily Requirements. Minimum Daily Requirements (MDR) are outdated standards set by the Food and Drug Administration for labels on foods and drugs. We will limit our discussion to Recommended Daily Allowances.

It is not necessary to obtain the recommended quantity of each nutrient each day. For instance, the one-day diet that you used for Activity 29 is probably deficient in some nutrient. This does not mean that you are suffering from malnutrition. Your body has the capacity to store certain quantities of nutrients, and it is only necessary that you obtain enough over a period of time. You should obtain enough nutrients for good health if the average quantity in your daily diet meets the Recommended Daily Allowance.

Activity 24 was a calculation of your daily energy expenditure. You determined how many calories you use up in a day. Your calculations were based on your actual weight.

It makes better sense, though, to base your calculations on what you should weigh, your ideal weight. For instance, if you weigh more than you should and you base your energy needs on your actual weight, you will tend to maintain your present weight. However, if you base your energy needs on your ideal weight, you will lose weight until you reach your ideal weight. In Laboratory Activity 30, you will determine your ideal weight.

30-2 Overweight or Obese?

How can a person be overweight and yet not obese?

The words overweight and obese have slightly different meanings. A person may be overweight without being obese. It is important that we distinguish between the two words.

Certain tables have been designed to give normal weights that are based on height, age and sex. For instance a table might state that a 20-year-old male who is six feet tall should weight 165 pounds. This table does not take into account the possibility that he may have large or small bones, or exceptional muscle development. If a person weighs more than the weight given for that person's height, age and sex, he or she is said to be overweight. Being overweight is not necessarily bad, because it says nothing about the amount of fat. It is possible to be overweight with almost no excess fat on the body.

Obesity, however, is defined in terms of the percentage of fat on the body. A male whose body is over 20 per cent fat or a female whose body is over 30 per cent fat is generally considered obese.

A male should have approximately 12 to 16 per cent fat, and a female about 18 to 24 per cent fat. Percentages greater than these are generally undesirable, although lower percentages are usually not harmful and often beneficial. In Laboratory Activity 30 you will determine what percentage of your body weight is fat, and from this you will calculate your ideal weight.

How does a person gain weight? The simplest answer is that a person gains weight when the energy content of the food eaten is greater than the energy expended by the body. Eat too much or exercise too little, and you gain weight. An approximate rule is that one pound of weight is gained for every 3500 calories that are supplied by food above the calories that are expended. It also works the other way: when the body expends 3500 more calories than are obtained from food a person loses a pound. Too little exercise may be the result of too little time or too little motivation or injury or illness. The causes of eating too much are often psychological. We will return to this subject when we discuss the treatment of obesity in a later section.

What is the difference between "Recommended Daily Allowances" and "Minimum Daily Requirements?" Which is presently used to describe dietary needs?

How does your body continue to supply you with dietary requirements during fasting periods (between meals), or periods when you are eating irregularly?

Why is it better to determine the number of calories expended per day based on "ideal weight" rather than actual weight?

At what point is an overweight individual considered obese?

If you had a choice, would it be better to be "overweight" or "obese?" Explain.

Vocabulary:

ideal weight--the amount a person should weigh for good health.

obesity--the condition of having too much body fat.

overweight--the condition of weighing more than the recommended weight in standard tables.

SECTION 31: THE OPTIMAL DIET

31-1 The Essential Ingredients

What do we mean by an "optimal" diet?

In this section we will review the nutrients required to enable us to function at our best level over a long period of time. We will continue the search for the best possible diet, the optimal diet. True, we can all "get by" on most American diets, no matter how careless they are, but are we functioning at our best? Do we have abundant energy or are we drowsy during the day? Are we healthy, or do we have many colds, minor headaches and stomach upsets? Certainly, diet plays a role in each of these conditions and, in this section, we will attempt to summarize the dietary factors needed for healthy functioning. Certainly, such an optimal diet would also have long-term health advantages.

In the sequence on nutritional chemistry we saw the recommended levels for minerals in our diet. Among the minerals discussed were calcium, phosphorus, iron, iodine, sodium and potassium. The use of these materials by the body and the foods rich in them were described in Sections 19 and 21.

Proteins, as a major component of many body structures, are extremely important in our diets. As we have seen, our bodies are unable to make certain amino acids and therefore they must be supplied in our diets. While eight amino acids are considered essential it has been found that if three of these are present in a food the other five essential amino acids are generally also present. These three amino acids are lysine, tryptophan and methionine. (This is why you determined the quantities in your diet of only these three amino acids in Activity 29.)

Carbohydrates, in the form of starches and sugars, are one of the two principal sources of energy in our diets (fat is the other), and must be carefully controlled for the reasons we have already outlined.

While the overall percentage of calories derived from fats should be lowered in most American diets, it is particularly important to lower the per cent of saturated fatty acids. In an optimal diet the proportion of polyunsaturated fatty acids should be at least as great as the proportion of saturated fatty acids. (Can you recall why polyunsaturated fatty acids are more desirable than saturated fatty acids?)

The Recommended Dietary Allowances of various vitamins were listed in Section 21. This is a good time to review those recommendations; while considering an optimal diet. At this point it can be said that if you take care of the primary nutritional needs, outlined in preceding paragraphs of this section, your vitamin needs will generally be taken care of.

31-2 Other Ingredients in the Optimal Diet

Why is "roughage" a dietary necessity?

By reading the first part of this section you might reason that a single pill containing all the essential amino acids, minerals and trace elements, vitamins and essential fatty acids could provide you with all your nutritional requirements. If this were true, aside from such miracle pills, food and eating might become a hobby for people who could get such pills!

Fortunately, the pleasure of eating is not likely to be eliminated. Aside from the fact that nutritional studies have not yet determined every possible nutrient contained in the variety of foods available in a supermarket, there is at least one constituent of foods that has not yet been put into a pill.

Roughage, which is found largely in fruits, vegetables and whole-grained breads and cereals, is necessary both to aid digestion and possibly to prevent certain diegestive tract diseases. Roughage, or fiber, is actually the indigestible cellulose cell walls of plant foods.

Although it is not broken down in our bodies and has no nutritional value, the fiber acts to aid defecation when it reaches the large intestine. People who eat high fiber diets produce large, soft feces that pass through the intestine in a little over one day. On the other hand, people who eat highly refined diets, with little fiber, pass feces that are small and stiff and take several days to pass through the intestine. This is why people who eat diets of refined food are often constipated.

Foods such as whole-wheat bread and high-fiber oats, fruits and vegetables, are excellent sources of dietary roughage. But remember to read labels on food packages very carefully. For example, in looking for whole-wheat bread,be certain to check the ingredients. If it says "wheat flour" you will not be buying anything but highly refined white flour, with very little fiber. Due to a loophole in the food labeling laws, the words "wheat flour" and "refined white flour" mean the same thing! To get genuine whole-wheat bread, a good source of fiber, the ingredients list must state that "whole-wheat flour" is present.

31-3 Too Much of a Good Thing

Can we discuss the optimal diet without mentioning those things in our diet which should not be present?

A great deal has been mentioned about the possible links between salt and hypertension, sugar and heart disease, saturated fatty acids and atherosclerosis. While absolute proof that these substances actually cause these diseases is not available, it may be wise to await such conclusive proof before making dietary modifications.

"Diseases of civilization," such as atherosclerosis, hypertension, and diabetes, are probably increased by the rich, sweet and salty diets in economically developed nations. Many examples that compare health in primitive and urbanized areas are in the literature. One brief example may serve to exemplify how "too much" can be as detrimental to health as "too little."

True, a large percentage of the world's population suffers from hunger and malnutrition as a result of poverty. However, an abundance of good food was generally available to people in the islands of the South Pacific. In one of these island groups, Rarotonga, or the Cook Islands, people traditionally ate fresh fruit and vegetables, nutritious root crops and much ocean fish. As the islanders, known as Maori people, emigrated to other countries their diets changed. The diets of Maoris in the Cook Islands and New Zealand, where many migrated, were compared. It was found that sugar and salt intake in the outermost Cook Islands, notably Pukapuka Isle, was only a fraction of that in New Zealand. All of the "civilized" diseases plus obesity occurred much less frequently in Pukapuka (population 800), while amongst Maoris in industrialized New Zealand disease rates were the highest. Medical scientists who studied these Maori people concluded that they became increasingly susceptible to the diseases of Western civilization the closer they came to adopting the dietary pattern of Westerners.

But too much sugar, salt, saturated fatty acids, and calories are not the only things to watch for in an optimal diet. Certain microbes do not belong in our foods and some food additives may be harmful.

31-4 Evaluation of a Meal

The following breakfast menu has been suggested as adequate; that is, it makes every calorie count. Few sugar-rich foods are present. In their place are tissue-building foods which are rich in protein, minerals, and vitamins. Yet this "ideal" breakfast is not perfect according to what we have seen thus far in the Nutrition Unit. See whether you can pick out the negative features of this menu. (Hint: You may assume the diet provides adequate vitamins and minerals.) Can you offer substitutions, or alternative foods which are nutritionally sound?

Adequate Breakfast

$\frac{1}{2}$ grapefruit, 2 eggs, 3 oz ham, 1 slice whole-wheat bread and butter, 1 glass of milk.

NUTRIENTS

calories	600
protein	45 g
carbohydrate	40 g
fat	40 g
ascorbic acid	50 mg
niacin	15 mg
riboflavin	1.07 mg
thiamin	0.8 mg
vitamin A	4200 IU
phosphorus	760 mg
calcium	460 mg
iodine	17 μg
iron	7 mg

List the essential ingredients required in an optimal diet.

Name three good sources of roughage or fiber.

According to the food-labeling laws, what is the difference between refined white flour and "wheat" flour?

What does not belong in our diets?

Can we devise one "optimal diet" that would be good for all people?

What is meant by "diseases of civilization?" What causes these diseases?

Vocabulary:

fiber--roughage

optimal diet--the ideal or best diet for an individual.

roughage (RUF-idg)--the indigestible cell walls of plant foods, required in our diets to stimulate intestinal action and promote peristalsis.

SECTION 32: DIABETES AND NUTRITION

32-1 Diabetes Mellitus

How is the hormone insulin related to diabetes mellitus?

We have considered diet in relation to the maintenance of good health; now we will turn our attention to the role of diet in the treatment of a disease. This section is devoted to the dietary treatment of diabetes mellitus, while the next section will concern obesity.

The word "diabetes" is applied to diseases that are characterized by excessive amounts of urine being excreted. One type of diabetes is caused by a shortage of a hormone that controls the absorption of water back into the blood from the kidneys. The water that is not reabsorbed leaves the body as urine. This type of diabetes does not concern us here, but a type called diabetes mellitus does. The word "mellitus" is from the Latin word for "honey" and refers to one symptom of diabetes mellitus, the sweet taste of the urine. This disease is the most common type of diabetes, and when the single word "diabetes" is used, it is generally diabetes mellitus that is meant.

Diabetes mellitus is characterized by impaired ability of the body's cells to use glucose. Therefore, we will briefly review the digestion of carbohydrates. During digestion, carbohydrates are broken down to monosaccharides, principally glucose. They are absorbed into the body, where other monosaccharides are converted to glucose. Glucose is carried by the blood to the cells, where it is used to provide energy. Excess glucose is stored by the liver as glycogen, and when the liver's capacity for storing glycogen is exceeded, glucose is converted to fat, which is also stored.

Within the pancreas is a group of cells with the poetic name of Islets of Langerhans. The function of these cells is to secrete a protein hormone called insulin into the blood.

Insulin helps glucose to enter into cells. It is not known how insulin helps, but it is known that when insulin is in short supply, the body does not use glucose efficiently. The resulting condition is diabetes mellitus.

Recall the discussion of insulin in connection with hypoglycemia. We examined a case history in which a snack of honey led to a high blood glucose level, which in turn led to a high insulin level. The large amount of insulin caused glucose to be metabolized (i.e., participate in cell respiration) more rapidly than it normally is; as a result the blood glucose level decreased to less than normal.

The system by which insulin controls the use of glucose is an example of negative feedback and of homeostasis. Glucose concentration increases; insulin secretion increases. Insulin concentration increases; glucose metabolism rate increases. Breakdown of glucose increases; glucose concentration decreases.

Normally the body has other mechanisms to correct the situation of high insulin and low glucose. However, in the case we considered, the mechanisms could not react sufficiently to counteract the imbalance, and the runner collapsed after his race.

Diabetes mellitus is a condition that involves insulin in another way. Either the pancreas does not secrete enough insulin, or the body's cells simply do not respond to the insulin that is secreted. In either case the result is the same: glucose is not effectively metabolized. The fact that glucose is not properly metabolized causes some of the symptoms of diabetes.

The concentration of glucose in the blood of a diabetic person is greater than in a normal individual, because glucose is not metabolized to the extent it should be. Glucose that is not used is eliminated, and extra water is required to remove unused glucose. A diabetic characteristically urinates frequently and is often thirsty. Since his cells do not receive sufficient energy (ATP), he tires easily. He may lose weight and be constantly hungry.

However, the high blood-glucose level and frequent urination are not the real dangers in diabetes; the dangers are what these symptoms lead to.

One of the complications of diabetes is disease both of the larger vessels (atherosclerosis) and of the small vessels. The occurrence of atherosclerosis again appears to be related to a high level of cholesterol and fats in the blood of a diabetic. Damaged blood vessels may cause other symptoms to develop such as heart disease. Vision may deteriorate, wounds heal slowly and poor circulation causes pain in the fingers and toes. If diabetes is not treated, it may be fatal.

What causes a person to have diabetes is not well understood, but it is known that diabetes tends to be inherited. Characteristically, some relatives of a diabetic will also have diabetes. Approximately five million Americans have diabetes. It is estimated that perhaps another five million will develop diabetes during their lives.

Physicians recognize two forms of diabetes mellitus. The more common form is adult-onset diabetes, which generally appears after the age of 25. Adult-onset diabetes is usually developed by overweight people. The other form is juvenile-onset diabetes, which appears before age 25 and is not related to being overweight. The symptoms of the two forms are essentially the same, and the two forms may have the same cause and are certainly related, but the symptoms characteristically become more severe when the disease first appears at a young age.

In Japan, the incidence of diabetes is increasing along with rising prosperity. This is thought to be related to an increase in the amount of food eaten, particularly the amount and types of carbohydrates.

How is diabetes detected? Two tests are done when diabetes is suspected; urine and blood are tested for glucose. A high concentration of sugar in urine is a sign of diabetes. However, high sugar concentration may also be caused by other factors, so this test is not conclusive.

If a urine test suggests diabetes, the diagnosis is confirmed with a series of blood tests. A blood sample is taken at least eight hours after the patient has digested and absorbed his previous meal. The concentration of glucose in this sample is the fasting blood glucose level. Each person has a specific fasting blood glucose level. The level in a normal individual is less than 110 mg of glucose per 100 ml of blood, but the level of a diabetic is greater than 120 mg of glucose per 100 ml of blood.

The patient is then fed 75 grams of glucose. The glucose is absorbed into the blood. In a normal individual the blood glucose level rises within an hour to perhaps 140 mg per 100 ml of blood (160 mg per 100 ml maximum). (See Figure 1.)

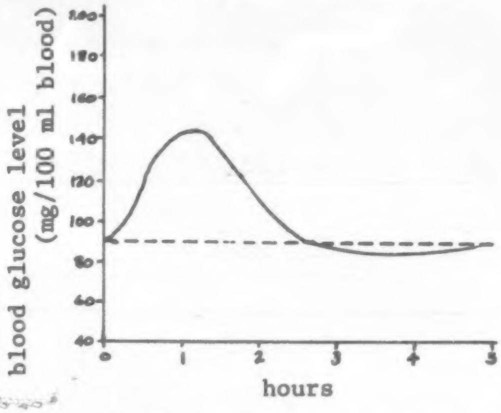

FIGURE 1: *Blood glucose level in a normal individual.*

The increase in blood glucose stimulates increased insulin secretion. The blood glucose level decreases after an hour, because the additional insulin causes faster utilization of glucose.

Note that the blood glucose level drops below normal after about three hours, then slowly returns to normal. The decrease below normal is explained by the extra insulin that was secreted. As the insulin level then returns to normal, so does the glucose level.

Compare the graph for a normal person to that of a diabetic individual. (See Figure 2, following page.)

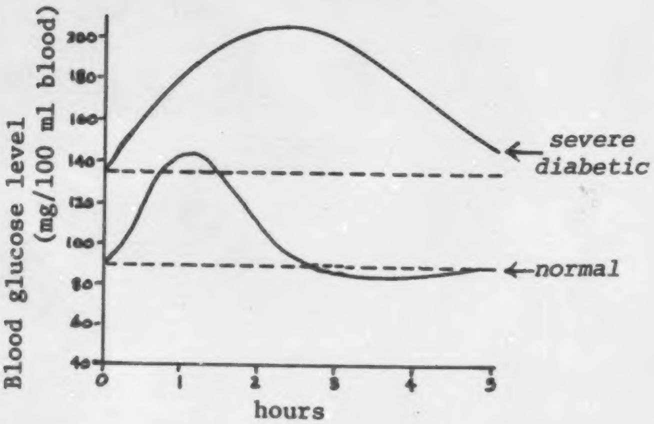

FIGURE 2: *Blood glucose level in a normal individual and in a diabetic individual.*

The fasting blood glucose level of the diabetic represented in the graph is approximately 135 mg per 100 ml of blood. After ingesting 75 grams of glucose, his blood level rises. Unlike a normal individual, his level does not decrease after an hour, either because he lacks insulin or because his body does not respond properly to the insulin he produces. Less glucose is metabolized, and the blood glucose level continues to rise. Eventually some glucose is metabolized and some is eliminated in urine. The blood glucose level then returns to the diabetic's fasting level. Diabetics can usually be diagnosed on the basis of this test.

32-2 Diet and Diabetes

How is diabetes treated?

Diabetes cannot be cured, but it may be controlled. The aim of treatment is to maintain a normal blood sugar level. Little or no glucose should be lost in the urine. There are two strategies for achieving this aim. These two strategies are insulin injections and control of diet; often both strategies are used. Juvenile-onset diabetes is commonly treated with both, adult-onset diabetes often only by controlling diet. Insulin reduces the level of blood glucose, but it must be injected, not taken orally. (Insulin is a protein, and if taken orally it is digested: converted to amino acids.) Pills that increase insulin secretion are available, but their value at present is in doubt.

The other strategy for controlling diabetes is diet. The primary aim is to eliminate sugar and reduce the amount of starch, which is converted into sugar. Sugars cause a rapid rise in blood glucose; this is undesirable, particularly in diabetics. The amounts of starches (rice, bread, potatoes, etc.) may also be reduced and distributed evenly throughout the day. Also, since diabetics are prone to developing atherosclerosis, their diets should minimize saturated fatty acids. At the same time the patient must obtain good nutrition.

Dietary treatment of a specific individual depends on his life style and the severity of the disease. Diabetes is aggravated by obesity, and the calories provided by a diabetic's diet must be restricted.

Diabetics must control their diets for the rest of their lives, and it is not realistic to expect a diabetic to perform detailed dietary calculations every day. A current trend is to educate a patient in the nutritional value of various types of foods, tell him what to emphasize in his diet and what to avoid (carbohydrates, especially sugar), and let him suit his diet to his own tastes and his body's reaction.

A more traditional approach to a diet for diabetes, however, is a system devised by the American Diabetes Association and the American Dietetic Association. The object of this system is to make calculations easier. It is based on the concept of food equivalents. Common foods are placed in categories according to their nutrient composition. Each category is called a "food exchange group."

There are seven food exchange groups: milk, meat, two vegetable groups, bread, fruit and fat. Shortened versions of food exchange groups are shown on the next two pages.

FOOD EXCHANGE GROUPS

Milk Exchange

Buttermilk, from skim milk, 1 cup
Dried skim milk powder, 1/4 cup
Dried whole milk powder‡, 1/4 cup
Evaporated milk‡, 1/2 cup
Homogenized or whole milk‡, 1 cup
Plain yoghurt‡, 1 cup
Skim milk, 1 cup
2% butterfat milk**, 1 cup

Vegetable A Exchange

(Up to one cup may be eaten at each meal without counting it.)

Asparagus
Beans, green or wax
Broccoli*+
Brussels sprouts
Cabbage
Cauliflower
Celery
Cucumber
Eggplant
Greens, all kinds*
  collard, kale
  spinach, etc.
Lettuce
Mushrooms
Parsley
Pepper, green*+
Radish
Sauerkraut
Tomatoes*
Vegetable juice

Vegetable B Exchange

(One serving equals 1/2 cup cooked vegetable or 1/2 cup raw vegetable.)

Artichoke
Beets
Carrots*
Onions
Peas, green
Pumpkin
Squash, winter*
  Butternut, acorn
Turnip

Fruit Exchange

(Raw, cooked, canned unsweetened, or frozen unsweetened)

Apple, 1 (2-inch diameter)
Applesauce, 1/2 cup
Apricots*, dried, 4 halves
Apricots*, fresh, 2 medium
Banana, 1/2 small
Blueberries, 2/3 cup
Cantaloupe+*, 1/4 (6-inch diameter)
Cherries, sweet, 10 large
Dates, 2
Figs, dried, 2
Grape juice, 1/4 cup
Grapefruit+, 1/2 small
Grapefruit juice+, 1/2 cup
Grapes, 12
Honeydew melon, 1/8 (7-inch diameter)
Nectarine, 1 medium
Orange+, 1 small
Orange juice+, 1/2 cup
Peach, 1 medium
Pear, 1 small
Pineapple, 1/2 cup cubed or 1 slice
Pineapple juice, 1/3 cup
Plums, 2 medium
Prunes, dried, 2 medium
Raisins, 2 tablespoons
Raspberries, 1 cup
Strawberries+, 1 cup
Tangerine+, 1 large
Watermelon, 1 cup

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*Rich sources of vitamin A.
+Rich sources of vitamin C.
**Omit 1 fat exchange from diet.
‡Omit 2 fat exchanges from diet.

Bread Exchange

- Bread, white, rye, whole wheat, 1 slice
  - Biscuit, 1 (2-inch diameter)
  - Cornbread, 1-1/2-inch cube
  - English muffin, 1/2
  - Frankfurter bun, 1/2
  - Hamburger bun, 1/2
  - Muffin, 1 (2-inch diameter)
  - Roll, 1 (2-inch diameter)
- Cake, plain and unfrosted angel or sponge, 1-1/2-inch cube
- Cereal
  - Cooked, 1/2 cup
  - Dry, flaked or puffed, 3/4 cup
- Crackers
  - Graham, 2 (2-1/2 inch square)
  - Round, thin, 6 to 8 (1-1/2 in. diam.)
  - Saltines, 5 (2-inch square)
  - Soda, 3 (2-1/2-inch square
- Flour, 2 1/2 tablespoons
- Ice cream‡, 1/2 cup
- Sherbet, 1/3 cup
- Noodles, spaghetti, cooked, 1/2 cup
- Rice or grits, cooked, 1/2 cup
- Vegetables
  - Baked beans, no pork, 1/4 cup
  - Beans and peas, dried, cooked, 1/2 cup
    - Black-eyed peas, kidney, lima
- Corn, popped (plain), 1 cup
- Corn, sweet, 1/3 cup or 1/2 ear
- Lima beans, fresh, cooked, 1/2 cup
- Mixed vegetables, 1/2 cup
- Potato, 1 (2-inch diameter) baked or boiled
- Potato, mashed, 1/2 cup
- Sweet potato or yam, 1/4 cup

Meat Exchange

- Cheese
  - American, Cheddar, Swiss, 1 ounce, 1 slice, 1-in cube, 1/4 cup grated
  - Cottage, not creamed, 1/4 cup
- Cold-cuts, 1 slice
  - 4-1/2-in diameter, 1/8-in thick
  - Bologna
  - Liverwurst
  - Salami
- Eggs, 1
- Fish
  - Cod, halibut, haddock, trout, snapper, etc., 1 ounce cooked
  - Crabmeat, lobster, 1/4 cup
  - Shrimp, clams, oysters, 5 small
  - Tuna, salmon, 1/4 cup
- Frankfurter, 1
- Peanut butter, 2 tablespoons
- Meat, poultry (no bone or visible fat)
  - 1 ounce cooked or 3 slices
  - Beef
  - Chicken
  - Corned beef
  - Ham
  - Lamb
  - Liver
  - Pork
  - Turkey
  - Veal

Fat Exchange

- Avocado, 1/8 (4-inch diameter)
- Bacon, crisp, 1 slice
- Butter or margarine, 1 teaspoon
- Diet-type margarine, 2 teaspoons
- Cream, whipping (40%), 1 tablespoon
- Cream, light (20%), 2 tablespoons
- Cream cheese, 1 tablespoon
- French or Italian salad dressing, 1 tablespoon
- Mayonnaise, 1 teaspoon
- Nuts, 6 small
- Oils or shortening, 1 teaspoon
- Olives, green, 5 small
- Sour cream 1 tablespoon

The virtue of the food exchange group system is not its accuracy. As may be seen from the table, its numbers are very approximate. Rather its virtue is the ease with which it may be used. Let us illustrate its use with an example.

You are a dietitian, and a physician has referred a patient to you. She has diabetes mellitus, and the doctor wants her calories limited to 1850 per day. The doctor also prescribes at least 80 grams of protein a day, with the remaining calories divided evenly between fat and carbohydrate. He specifies the carbohydrate distribution as 2/7, 2/7, 2/7, 1/7. The fractions indicate that 2/7 of the carbohydrate is to be eaten as breakfast, 2/7 at lunch, 2/7 at dinner, and 1/7 as an evening snack. The purpose of this distribution is to spread carbohydrate consumption as evenly as possible through the day. (A patient also receiving insulin injections would have a large amount of carbohydrate prescribed for the time of the injection, because the insulin would help metabolize the glucose formed in digestion.)

An example of a diet which would meet the physician's specifications is shown on the following page. Many diets could fit the prescription; the one shown was most appealing to the patient.

The patient has a diet prescription that she may use every day. She may eat any food within each group, provided she eats the amounts specified. Remember that a milk exchange is based on skim milk. She is free to drink whole milk if she wishes; but if she does, she must subtract two fat exchanges from that meal.

One drawback of the food exchange groups is that no attention is given to vitamins and minerals, other than noting a few foods rich in vitamins A and C. For this reason a dietitian must educate a patient to avoid his making choices such as a doughnut over a good type of bread.

You may be surprised to note that the diabetic's diet is not so different from your own optimal diet. The two in fact have the same ideals in common: sufficient amount of high-quality protein, sufficient amounts of vitamins and minerals, and minimum amounts of saturated fatty acids and sugar. The most important difference is that the diabetic must observe his diet conscientiously. If he has a banana split after school, or gains a few extra pounds, the results can be more immediate and drastic.

What is known about the cause of diabetes?

What is the function of insulin in glucose metabolism?

What complications result from diabetes?

How is diabetes detected?

What dietary modifications are necessary in controlling diabetes? What are some foods that you would not expect to find in the prescribed diet of a diabetic?

	Number of exchanges	Protein grams	Fat grams	Carbohydrate grams	Calories
BREAKFAST					
Fruit	1	--	--	10	40
Meat	2	14	10	--	146
Bread	2	4	--	30	136
Fat	3	--	15	--	135
Milk	1	8	--	12	80
TOTAL		26	25	52	537
LUNCH					
Bread	2	4	--	30	136
Meat	2	14	10	--	146
Milk	1	8	--	12	80
Fat	2	--	10	--	90
Fruit	1	--	--	10	40
TOTAL		26	20	52	492
DINNER					
Meat	4	28	20	--	292
Veg. B	2	4	--	14	72
Bread	2	4	--	30	136
Fat	2	--	10	--	90
Fruit	1	--	--	10	40
TOTAL		36	30	54	630
SNACK					
Bread	1	2	--	15	68
Fat	1	--	5	--	45
Milk	1	8	--	12	80
TOTAL		10	5	27	193
DAY'S TOTAL		98	80	185	1852

Vocabulary:

diabetes mellitus (DY-uh-BEE-teez muh-LY-tus)--a disease in which glucose is not metabolized effectively due to insufficient insulin or a failure of insulin to function properly.

fasting blood glucose level--the concentration of glucose in the blood eight hours or more after eating.

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SECTION 33: CASE HISTORY: OBESITY

33-1 Obesity

What causes weight gain?

When more energy is consumed than expended we gain weight. This is a primary fact of metabolism. Too many calories may lead to a state of obesity, the condition characterized by having more body fat than is healthy.

In Laboratory Activity 30 you determined your ideal body weight. You did so by measuring the percentage of your body that is fat. We distinguished between being overweight and being obese. Being overweight means having a weight greater than that given in standard tables. It may be due to excess fat, or it may be due to a heavy frame or more than normal muscle development, and is not necessarily bad. Obesity, however, is defined in terms of fat. A male with over 20 per cent fat or a female with more than 30 per cent fat is considered to be obese.

In this section we will mention briefly reasons for becoming obese and the effects of obesity on health. We will then discuss how the condition of obesity may be effectively and safely treated.

We will begin with a case history that illustrates many of the causes of obesity.

33-2 Case History: Female, Age 40

Mrs. Jones is 40 years old, 5 ft 4 in tall and weighs 153 lb. She has three boys aged 17, 15 and 14 years. Before her first child, she was very active and held a full-time job. However, when her first child was born, Mrs. Jones quit her job and devoted all her time to raising her child. Even though the child kept her busy and on her feet all day, she found it difficult to take off the excess pounds that remained after her pregnancy. The two succeeding pregnancies also added extra pounds to Mrs. Jones' weight that again were difficult to lose. She didn't keep gaining weight, at least not while her children were young. Those extra pounds just seemed to stay.

The bulk of Mrs. Jones' weight gain has come since her children grew old enough to do things for themselves. She no longer has to run around all day feeding the children, supervising their play, and picking up after them. Her hectic, run-around-the-house days have changed to fit her children's activities. Now, most of her time is spent driving the car--carting the boys to many of their different activities, doing the shopping and running other errands. When asked about getting more physical exercise, she replies, "But I do the housework and I'm always carting the kids around. I am busy all day and really exhausted at night. There never seems to be any time left for me to do anything more."

Her teenage boys are always hungry, so Mrs. Jones keeps plenty of snack items on hand. She believes the boys need something to munch on after school to keep their energy up. These snacks include crackers, potato chips, cookies, sodas and other sweets. Mrs. Jones also admits to munching on these items as she does her housework, just because they are there. She nibbles all day and then eats a big dinner with her family. Dinners usually consist of rich gravies and sauces, lots of bread and potatoes, some vegetables (but not much), meat and rich desserts. Her family has distinct likes and dislikes when it comes to eating. Since Mrs. Jones no longer has to spend time chasing the children, she can spend more time in the kitchen preparing meals her family will like. Mrs. Jones likes to cook. Being creative with her meals is the only interesting part of her housework drudgery. And, of course, she likes to eat, too.

Dieting has never appealed to Mrs. Jones because good food is an important part of the Jones' way of life. The family has always eaten their morning and evening meals together. By eating different foods than her family, she would spoil the feeling of togetherness. Besides, finicky eaters are not allowed at the table. Everyone eats the same foods. The food budget is fairly limited.

Mrs. Jones has never been active in social affairs. She does not belong to the school PTA, the church group or the local charity. Thus, Mrs. Jones is not socially pressured to lose weight. Her husband's complaints are not very harsh and her children don't seem to mind. Mrs. Jones is just not motivated to lose weight. She says, "What does it hurt to be overweight? If I had a job or something, then maybe...."

33-3 Treating Obesity

What are some steps that an obese person can take to lose weight?

The basic reason that someone gains weight is that more food is consumed (or more calories, if you wish) than is required for bodily needs. The reasons why someone consumes too much food, however, are more complex. We may mention several factors in the case of Mrs. Jones.

One factor is her changing energy requirements. Before she had her children she worked and had more exercise. She needed more food. And raising young children requires a great deal of energy. But as children grow older they are better able to care for themselves and require less effort from their mother. Thus Mrs. Jones was expending less energy than when she was younger.

Another factor is the change in metabolism with age. As they grow older, many people's basal metabolic rates decrease somewhat, so their bodies require less fuel.

Mrs. Jones was expending less energy, but her consumption of chemical energy in the form of food did not decrease correspondingly.

In fact, there is some evidence that her food consumption had increased. When she had a job, it is unlikely that snacks were available to nibble on throughout the day.

Mrs. Jones' preferences in foods are also a factor. Several of the foods mentioned supply a large number of calories: gravies, rich desserts, bread and potatoes, for instance.

There are a variety of reasons why people eat too much, most of the reasons being mental rather than physical. Some people eat when they are nervous; a person trying to stop smoking often complains of gaining weight. Others overeat when they are angry or depressed. But this is not the case with Mrs. Jones; she eats too much because she simply likes the taste of food and because she is in the habit of eating big meals with many snacks between them.

One condition that is commonly thought to lead to obesity is hypothyroidism. You may recall that the thyroid gland secretes the hormone thyroxin that helps determine our basal metabolic rate. When hypothyroidism exists, the thyroid gland secretes too little thyroxin. The result is that the basal metabolic rate is less than normal. Less energy is expended, so unless correspondingly less food is eaten, or the condition is treated with supplements of thyroid hormone, weight gain may result. But, since hypothyroid people generally have poor appetites, they are almost never obese.

The relation between obesity and beauty is a matter of personal preference, but the relation between obesity and health is not. There are many indications that obesity is detrimental to good health.

A larger percentage of obese people than normal people develop atherosclerosis, hypertension, diabetes mellitus and arthritis. And obesity makes surgery more risky. For one thing, if a surgeon has to cut through excess fat, it is more difficult to find what he is looking for. Also, an obese person is usually not as healthy as a person who maintains an ideal weight, and during surgery it is important that a person be in as good a condition as possible. In the Framingham Study, the rate of sudden death from coronary heart attack was found to be almost five times greater for men who were 20 per cent or more overweight than for men who were not.

Let us return to Mrs. Jones. What are we going to do about her obesity? (We'll ignore the fact that diets should be prescribed by specialists.) If she likes being obese, of course, it is none of our business; and she is free to live as she pleases. But few people like being obese. If she does decide to lose weight, what is the best course for her to follow?

The first principle of losing weight is to expend more energy than is consumed. 3500 excess calories are equivalent to about a pound of excess weight. A person loses about one pound for every 3500 calories that are expended without being restored from food. So exercise helps one to reduce weight. Exercise increases energy expenditure, and it also improves muscle tone. This prevents tissues from becoming flabby after weight is lost. But it takes a lot of exercise over a long period of time to produce a significant effect. It does not appear from her case history that Mrs. Jones does much exercising, but rather spends her time around the house or in her car.

Weight is also lost by reducing the number of calories in our diets, but restricting our intake of calories too drastically is not a good idea. Our bodies still need protein, vitamins and minerals. In addition, losing weight too rapidly makes it difficult for our bodies to adjust to the change.

A person may also have psychological difficulty adjusting to a very restricted diet. Hunger, irritability and depression are hazards of such a program. It is better to lose weight slowly, to develop food habits that keep our bodies at their ideal weights once we get there.

For these reasons it is generally advised that a calorie deficit be no more than 1000 calories per day. 1000 calories per day is 7000 calories per week. A deficit of 7000 calories results in a weight loss of about two pounds. So two pounds per week is considered a safe rate at which to lose weight.

Let us plan a specific program for Mrs. Jones, assuming that she has decided to lose weight. Her ideal weight is determined to be 125 pounds, but her present weight is 153 pounds, so she should lose 28 pounds.

Mrs. Jones writes down her diet for a typical day; it provides her with 2300 calories. She requires nearly 2300 calories per day to maintain her weight at 153 pounds. If she weighed 125 pounds, her ideal weight, she would need only 1875 calories daily. This argument assumes that Mrs. Jones would be as physically active at 153 pounds as at 125 pounds.

If we put Mrs. Jones on a diet of 1875 calories, she would begin to lose weight slowly. But since she should lose two pounds a week, we reduce her energy intake to 2300 - 1000 = 1300 calories per day.

Mrs. Jones should get about 0.8 gram of protein per day per kilogram of ideal body weight. 125 pounds is approximately 57 kilograms, so her diet should include 57(0.8) ≃ 46 grams of protein. 46 grams of protein supplies about 46 x 4 = 184 calories.

The remaining 1300 - 184 = 1116 calories will be supplied by fat and carbohydrate. 40 per cent of the 1116 calories, or approximately 446 calories, will be supplied by fat. The remaining 60 per cent of 1116 calories, which is 670 calories, are supplied by carbohydrate. 446 calories are provided by 446 ÷ 9 ≃ 50 grams of fat. 670 calories are supplied by 670 ÷ 4 ≃ 168 grams of carbohydrate.

So Mrs. Jones is restricted to a diet of about 46 grams of protein, 50 grams of fat and 168 grams of carbohydrate. This diet will enable her to lose weight, beginning at a rate of two pounds per week, until after a few months she reaches her ideal weight.

When her weight becomes 125 pounds, her energy intake will be adjusted to 1875 calories. This number of calories will enable her to maintain her weight at 125 pounds.

A more specific diet for Mrs. Jones would consider several factors. One is that her diet must include sufficient amounts of all vitamins and minerals. Another consideration is that her diet should fit her family's eating habits as well as possible. Continuing to eat the same foods as her family, even though in smaller quantities will make dieting easier and avoid the trouble and cost of preparing separate foods.

We should also teach her some facts about nutrition: how foods with fewer calories may be substituted for higher-calorie foods. Substituting lean meat for fat meat, nonfat milk for whole milk, and cooking oils for solid fats, are examples of changes that she may make without seriously upsetting the family eating habits. And we can point out the advantages of salad (with low-fat dressing) with dinner. If Mrs. Jones still insists on snacks, they must be considered in her allotment of calories.

If Mrs. Jones goes to a bookstore, she is likely to find an entire shelf devoted to books on losing weight. Each book claims to advocate the best method, but they generally contain a serious flaw. It is well to ask several critical questions before adopting a plan from any book on losing weight.

Other weight-loss plans involve drugs that cause the body to lose not fat, but water. Losing water is not desirable and is not weight permanently lost. Many devices, such as plastic suits, also involve water loss and therefore do not involve true, permanent weight loss.

Many diets that cause too rapid a loss of weight also cause serious problems. Some promote a loss of muscle tissue rather than fat. Some create a deficiency of essential vitamins and minerals. An ideal diet should meet all nutrient requirements, not by pills but in the food.

A question that should be asked about any diet is whether the balance of protein, fat and carbohydrate is good. If too little carbohydrate is included in a diet, another difficulty occurs. Our cells are suited to obtaining energy by metabolizing fat in combination with carbohydrate. When no carbohydrate is available, fat is brought from fat deposits to cells to use for energy. One of the breakdown products of fats is an acidic substance called a ketone body. Normally, the amount of ketone bodies in the blood is low because carbohydrate is metabolized for energy instead of fat. However, with the increased metabolism of fats, the concentration of ketone bodies in the blood increases, causing the blood pH to decrease. This condition is called ketosis.

Because too much protein, too little carbohydrate or too much fat all create problems, it is desirable that a weight-loss diet contain roughly the proportion of fats, carbohydrates and proteins that your optimal diet does.

What must be true about energy consumption and expenditure for a person to lose weight?

Review the case history and list some of the reasons why Mrs. Jones was obese.

How is obesity treated?

What is hypothyroidism? Is this condition a common cause of obesity?

Are obese people particularly prone to any diseases? Name them.

Vocabulary:

ketone body (KEE-tone)--by-products of fat metabolism when carbohydrates are not available.

ketosis (kee-TOE-sis)--a condition in which ketone bodies accumulate and cause the blood pH to drop.

hypothyroidism (HY-po-THIGH-royd-izm)--a condition in which there is an insufficient production of thyroxin; opposite of hyperthyroidism.

REVIEW SET 33:

1. a. State the Law of Conservation of Energy.

   b. Does it pertain to energy changes in metabolism?

2. Which of the following may be expressed in units of calories?

   a. The mass of vitamins in a food.

   b. A quantity of heat.

   c. The amount of chemical energy in a mole of glucose.

   d. The amount of energy made available to the body by the conversion of a mole of ATP to ADP.

   e. The temperature of the human body.

   f. The kinetic energy of a rolling ball.

3. Plants produce glucose from carbon dioxide and water by photosynthesis. (This process is also the main source of the oxygen of our atmosphere.)

$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2 \qquad \Delta H_r = +673\ \frac{\text{kcal}}{\text{mole of glucose}}$$

a. Is photosynthesis exothermic or endothermic?

b. Is energy conserved in the process?

d. If it is released, in what form? If it is absorbed, can you suggest the source of the energy? (In other words, where would plants get energy for production of glucose?)

4. Ten grams of fructose ($C_6H_{12}O_6$) are oxidized in a calorimeter.

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

The calorimeter contains 3.75 kilograms of water, and the reaction raises the temperature of the water 10 °C.

a. How much heat is released by the reaction?

b. How much heat is released per gram of fructose? Express your answer both in kilocalories and in nutritional calories.

c. If fructose is first converted to glucose, and then the glucose is oxidized, how much energy is released per gram of fructose?

5. The combustion of octane produces CO_2, H_2O and 1303 kilocalories of energy per mole of octane.

$$C_8H_{18} + 12\tfrac{1}{2}\ O_2 \rightarrow 8\ CO_2 + 9\ H_2O + 1303\ \text{kcal}$$

a. What is ΔH_r for the reaction?

b. Is the reaction exothermic or endothermic?

c. What is the molecular weight of octane? (Use atomic weight of C = 12; atomic weight of H = 1.)

d. How many kilocalories (or nutritional calories) are produced per gram of octane?

6. What are the two different ways in which respiration is defined?

7. a. What is accomplished in glycolysis? In the rest of cell respiration?

b. How is the overall process related to nutrition?

8. What role do each of the following play in cell respiration?

   a. enzymes
   b. vitamins
   c. fats
   d. organelles

9. What is the relation between ΔH_r and the position of an equilibrium?

10. Suppose that there are more reactants than products at the equilibrium point of a reaction. What can be inferred (if anything) about the following?

   a. K_{eq}
   b. ΔH_r
   c. exothermic or endothermic
   d. rate at which the reaction proceeds

11. Consider the hydrolysis of ATP.

   a. Write the equation for this reaction.
   b. Why is this reaction biologically important?
   c. Is the reaction exothermic or endothermic?
   d. What can be stated about K_{eq}?

12. Give examples of different kinds of equilibria. Which of these are dynamic and which are static?

13. Do all individuals need the same amounts of all nutrients? Explain.

14. In what form is most dietary sodium consumed? Which foods are particularly rich in sodium?

15. Which minor ailments may be the result of some foods we eat?

16. Why is it particularly important to lessen the amount of saturated fatty acids in our diet while increasing our intake of polyunsaturated fatty acids?

17. Name five foods which are likely to be rich in saturated fatty acids.

18. a. What is the importance of roughage in the diet?

   b. Which foods are good sources of roughage?

19. What is diabetes mellitus?

20. Is obesity an illness? Why?

21. What is the first principle of losing weight?

SECTION 34: FOOD AND WATERBORNE DISEASES

34-1 The London Epidemic of 1854

Why were so many people getting cholera?

The year was 1854, the place London. A severe epidemic of an intestinal disease called cholera had occurred. People were suffering from severe intestinal cramps, fever, and diarrhea. The water loss from the body because of the diarrhea was so severe that people were dehydrating badly. No one knew what caused it and hundreds were dying, but a shrewd physician, Dr. Snow, had an idea. He got hold of a map and marked the streets containing the homes where people were sick. This led him to notice something: first, most of the homes were in the same section of London, and secondly, most of these homes surrounded a water pump on Broad Street. (In those days, most city dwellers had to fetch their water from a pump in the street.) Dr. Snow reasoned that whatever it was that caused cholera was in the water from that pump, and that when people drank it, they got sick. When the pump was officially closed down at Dr. Snow's prompting, the epidemic ended, and Dr. Snow was a hero.

It was the first time in history that a disease was definitely shown to be transmitted in drinking water. Today, we know that cholera is caused by a bacterium called *Vibrio cholerae*.

This story illustrates our new subject: food and waterborne diseases. It is the subject of this and the next several sections. Most of the diseases that come from food and water are caused by microbes, which is the name given to microscopic living things, such as cholera bacteria. But we must not overlook the fact that chemicals in our water supply and food may cause disease problems, too. These come from the chemical pollution of water, and possibly from the chemical additives used in manufacturing foods. Lastly, we will consider how the altering of foods during manufacture, such as by canning, changes the makeup of nutrients, and how this is related to health.

All of these subjects will be explored in this sequence of sections. First, in this section and the next one, the diseases caused by microbes in food and water will be examined.

34-2 Good Bacteria, Bad Bacteria

How many bacteria are inside us?

Epidemics of diseases carried by food and water once caused great suffering in the U.S. These epidemics included cholera, typhoid fever, and bacillary dysentery, all caused by bacteria. Bacteria are one of the kinds of microbes. Other microbes include viruses, and another type are the parasites, such as microscopic worms and single-celled animals called protozoa.

Each class of microbes may cause disease. In the study of respiration you saw that certain bacteria cause croup and pneumonia, while viruses cause influenza.

Most of the diseases carried in food and water, such as cholera, are caused by bacteria. This gives bacteria a bad name to most people. But very few of the many types of bacteria cause disease. In fact, many bacteria are important to us. They are found wherever there is life--in the soil, the ocean, the air, food, water, and even inside us.

Your digestive tract is loaded with harmless bacteria. When babies are first born they don't have any--their digestive tracts are sterile. But in a matter of days, the harmless bacteria that enter the gastrointestinal tract with the baby's food multiply and remain. How many are there inside? The stomach has few because its acid kills most of them. The large intestine, on the other hand, has many--about 100 billion bacteria in every gram of contents! In fact, feces are about 10 to 20 per cent bacteria. Some of the bacteria inside us do things that are useful. They make at least two vitamins: vitamin K and folic acid. (Incidentally, these vitamins are exceptions to the rule that vitamins are obtained directly from the diet.)

Some kinds of bacteria even make food. Cottage cheese is made by adding a culture of bacteria with the name *Streptococcus lactis* to milk. (Figure 1.) These bacteria quickly multiply and make lactic acid, which hardens the protein in milk into cheese. And in case you ever wondered, the holes in Swiss cheese are formed by carbon dioxide gas bubbles given off by certain bacteria.

Vibrio cholerae, 1000x *Streptococcus lactis, 1000x*

FIGURE 1: *The microscopic appearance of two bacteria.*

34-3 How Are Foodborne Diseases Spread?

We've just considered the fact that our gastrointestinal tract is normally loaded with harmless bacteria. Sometimes, however, disease-causing bacteria enter a person's intestinal tract. When they leave the body along with the feces, and if these feces contaminate food or water, the disease may spread to other people. (You may recall that this was the problem with infectious hepatitis.)

For example, epidemics of cholera and typhoid fever can occur when feces from sewage contaminates the drinking water supply as had occurred on Broad Street. And, in the case of contaminated rivers, lakes, and beaches, fish or other animals caught in such waters may also contain the bacteria. This is why there are strict laws governing the sanitary quality of drinking water, and why warnings are posted near contaminated bodies of water.

Another potential source of infection is milk. Milk normally contains harmless bacteria, but to kill any harmful ones that may be present, the milk is pasteurized. The usual procedure is to heat the milk to 63 °C and allow it to cool slowly. The harmful bacteria, such as the ones that cause tuberculosis, are killed in this way, but many harmless ones remain in the milk. Pasteurization does not sterilize milk. It makes it sanitary.

But most foodborne disease comes from fecal contamination. An outbreak of *Salmonella* disease (which has nothing to do with salmon--it's the name of the bacteria) once occurred because eggs were shipped in the same truck used to ship infected animals. A tiny bit of the animal feces got onto the outside of the eggs. Bacteria may also be spread by flies and other insects which touch feces and then land on food. And then there was the case of Mary Mallon, better known as "Typhoid Mary," a cook whose food resulted in 51 cases of typhoid fever. She was not sick herself, but the typhoid bacteria were living in her intestines. As a result, she was a constant source of infection. She transferred the bacteria while cooking. She was what is called a carrier, someone who is not sick but who harbors disease organisms. More strict food-handling laws have made "Typhoid Marys" a rarity.

34-4 Symptoms of Food and Waterborne Disease

How do we recognize harmful bacteria in the GI tract?

Disease-causing bacteria from food or water cause severe irritation to the intestinal wall either by attacking it directly or by secreting poisonous chemicals called toxins. A person will start to feel sick from 2 to 24 hours after ingesting the bacteria. As the intestine is irritated, the person may experience intestinal cramps, nausea, vomiting, loss of appetite and/or diarrhea. People don't always experience all of these symptoms--sometimes only one of them. Sometimes there is fever and headache, too.

In cholera the diarrhea is so severe that is causes dehydration. The water balance of the body is disturbed. It is treated by putting fluid directly into the bloodstream. Before this technique was developed, many thousands died of this disease.

Gastrointestinal disease can be caused not only by bacteria but also by protozoa and viruses. Infectious hepatitis, covered in Section 9, is an example of a viral disease. This virus is present in the feces of infected individuals and may be found in water contaminated with sewage. And then there's the common viral stomach "flu," which can result from several different viruses. Its symptoms are similar to those of the bacterial diseases, and also include weakness, dizziness, and muscular aches.

34-5 Food "Poisoning"

How can food "poisoning" be prevented?

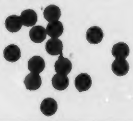
In the United States, food "poisoning" is the most common bacterial intestinal disease. Typhoid fever and cholera by comparison are now rare although they sometimes cause severe epidemics in less developed countries. There are two main mechanisms of food "poisoning."

1. The bacteria growing in the food produce a toxin which irritates the GI tract. This is how staphylococcal bacterial food poisoning works.

2. The bacteria attack the GI tract directly without secreting a toxin. *Salmonella* bacteria work this way.

In food "poisoning" bacteria grow in food before it is eaten, so when it is eaten, disease occurs. A little knowledge can help prevent it. The most important fact is this: bacteria grow best within certain temperature ranges. This means that the best way to prevent bacteria from multiplying in food is to refrigerate it or cook it at the appropriate temperature for a sufficient length of time. Most food poisoning is caused by three kinds of bacteria. The table below lists them, and the kinds of foods they usually grow in.

Leaving certain foods out of the refrigerator even for a few hours can give disease-causing bacteria enough time to multiply into a large enough number to cause trouble. In the next section, we will examine diseases caused by microbes other than bacteria.

Disease	Name of Bacterium, and shape	Foods usually involved
Staphylococcal Food Poisoning	*Staphylococcus aureus* 	Custard or cream filling in pastries; cured, processed, or leftover meat; potato salad; cheese; and milk
Salmonella disease	Several *Salmonella enteritidus* *Salmonella cholerasuis* 	Egg salad, cream in bakery goods, ground meats.
Perfringins poisoning	*Clostridium perfringins* 	Meat and poulty dishes, gravies.

What causes most food and waterborne disease? List three major types of microbes.

Name a useful function performed by bacteria within the human body.

How did "Typhoid Mary" transmit typhoid fever? How might these cases have been prevented?

Vocabulary:

carrier--a person or animal who carries, and may therefore spread, disease organisms without being sick himself.

culture--population of microbes grown on a medium.

microbe (MY-krobe)--a microscopic living thing, such as a bacterium, virus, or certain worms.

pasteurize (PAST-you-rise)--to make milk or other food products sanitary by heating.

protozoa--(PRO-tuh-ZOE-uh)--single-celled animals.

sanitary--free of disease-causing microbes. Sanitary things can still have harmless microbes.

sterile--free of all microbes, even harmless ones.

toxin (TOX-in)--a poisonous chemical made by bacteria or other living things, such as plants, snakes, and scorpions.

SECTION 35: PARASITIC DISEASES

35-1 Case History of Trichinosis, a Parasitic Disease

What caused Jim's cramps?

As Jim sat in Dr. Rogers' waiting room, he wondered. It had started three weeks ago: diarrhea, fever, cramping pains in his intestines, and nausea. He had gone to see Dr. Rogers back then and the medicine he had given him had made it better... for a while.

Now he was back to see the doctor again. He still had gastrointestinal problems: the cramps had never quite gone away. And in the meantime his eyelids had swollen, his eyes hurt and his tongue hurt when he moved it. The fever was pretty bad, too.

Jim told all this to the doctor.

"Let's have a look," said Dr. Rogers. He examined Jim's swollen eyelids. His eyes looked very inflamed--the whites were bloodshot. When he looked in Jim's mouth, there were tiny red spots on the underside of his tongue. Everything else in the exam was normal.

"Could be some virus," said the doctor, "but somehow I don't think so. We'll do some lab tests. First a CBC--that is, a complete blood count. It'll take an hour and a half for the results to come. In the meantime we'll give you aspirin for the discomfort and fever."

Jim had a blood sample taken and then sat around in the lobby looking at magazines. A while later he was back in Dr. Rogers' office.

"Looks like something significant in your blood here," the doctor said. "Your blood has an unusually large number of eosinophils. This kind of cell increases in number in an allergy."

"The swelling around your eyes could conceivably be hay fever, or an allergy to some food, or maybe you have poison oak.

"No," answered Jim. "Not as far as I know."

The doctor thought a minute. "Well, the number of eosinophils also increases in diseases caused by parasites. For instance, there's one type that comes from eating pork that's not cooked enough."

"Love eating pork. Just a few weeks ago, in fact, I went to a barbecue at a friend's house. They raised the hog themselves and butchered it. They live out on a small farm."

"Well, we'll test you for parasites. It'll call for more blood samples and we'll also run a test on your feces."

* * *

The next day Jim was back at the doctor's office.

"One of the blood tests is positive. What you've got isn't too serious though--it'll clear up with medicine in a few days. Looks like a case of trichinosis--that's when certain microscopic worms invade your intestines and then other parts of the body--in your case it's the eye muscles and the muscle tissue in your tongue, which is why there's pain and swelling there. The worms are called *Trichinella*. We searched for other kinds of parasites in your stool specimen but there was nothing. You're not the only one who's got it, either. I just got a notice from the Health Department. Seems a few cases of trichinosis have turned up lately. Anyway, we'll give you a drug that kills these worms. I bet you'll be feeling a lot better in a few days."

"I feel a lot better already, Doc," said Jim, "But I never would've expected worms."

35-2 The Life Cycle of a Parasitic Worm

How did the Trichinella *worm cause Jim's symptoms?*

It turns out that Jim's symptoms are easy to explain. They result from the way the *Trichinella* developed inside him. The way a worm develops and reproduces is called its life cycle. (This term is used to describe the stages of development and reproduction of any organism, including human.)

The pork Jim ate contained tiny larvae--small and immature worms (Figure 1A). These larvae are protected inside a case. The case with its larva inside is called a cyst (Figure 1A). (In medicine, the word cyst also means a swelling filled with fluid. We are not talking about this kind of cyst here.)

In Jim's gastrointestinal tract, the cysts dissolved and released the larvae (Figure 1B). The larvae then quickly grew into adults (Figure 1C) and the adults mated. After mating, each adult female gave rise to thousands of larvae in the intestines. This is when Jim first got sick with diarrhea, nausea, abdominal pain and fever.

These larvae are equipped with sharp spear-like tips (Figure 1D). Using their tips they bore through the intestinal wall and enter the bloodstream, which carries them throughout the body. Then they usually end up in muscles. (In Jim's case it was the muscles around his eyes and in his tongue.) Burrowing into muscles, the larvae form cysts. This causes swelling, which is a common response in disease. At the end of their life cycle, the cysts remain in the muscles, sometimes for as many as 20 years. The amount of injury done depends upon the numbers of cysts. Treatment with drugs kills them.

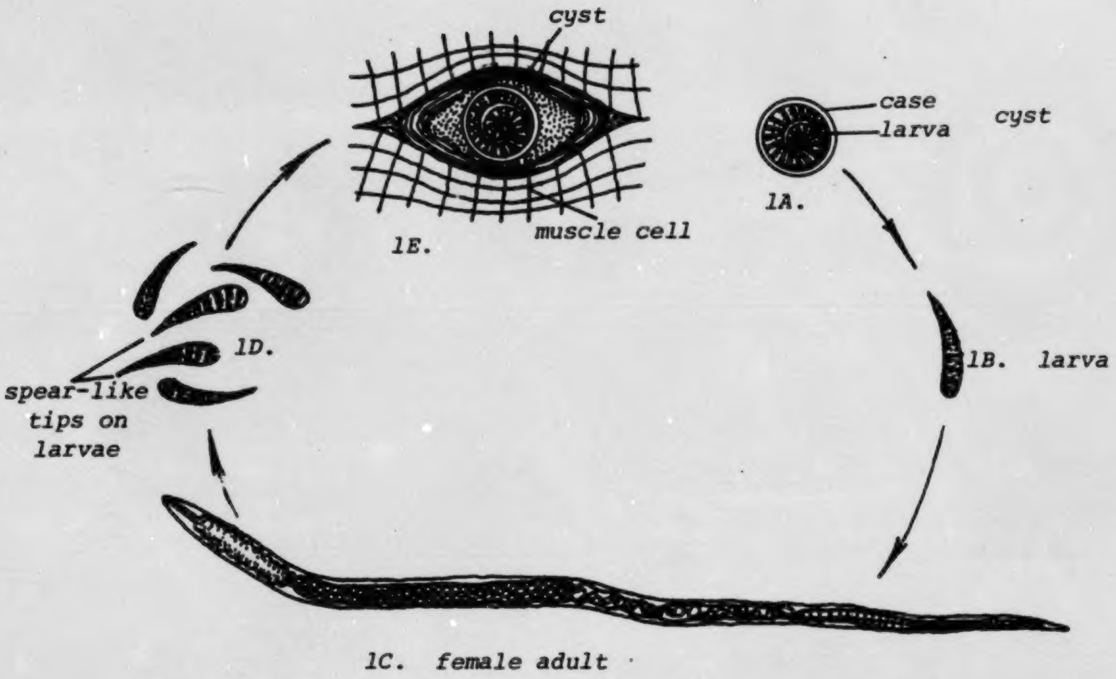


FIGURE 1: *The life cycle of the* Trichinella *worm in the human. Magnified 50 times.*

How did the pig that Jim ate get trichinosis in the first place? Pigs get trichinosis the same way humans do--by eating infected meat that hasn't been cooked enough. Today, laws require that only cooked meat be fed to pigs.

At one time, 15 per cent of the U.S. population had *Trichinella* cysts in their muscles. Most of these people never even felt sick because they had so few cysts. Today, less than 5 per cent of our people have cysts. The decline in trichinosis has been due to:

1. a decrease of trichinosis in pigs,
2. a decrease of pork in the diet compared to beef,
3. better freezing methods, which kill the larvae in pork,
4. increased acceptance of the importance of cooking pork.

Pork should be cooked so that the meat is heated to at least 55 °C (131 °F) throughout. One way to tell whether pork is properly cooked is to make sure the pink color deep inside disappears and becomes brown. (Ham, of course, remains pink at much higher temperatures.) There is no practical way for the food processor or farmer to inspect pork for cysts. As a result, much of the responsibility for prevention rests with the consumer.

One final point: the Talmud (an ancient book of Jewish laws) forbids the eating of pork. This tradition may have had its roots in preventing trichinosis.

35-3 What Is a Parasite?

Trichinosis is one of many diseases caused by parasites. A parasite is an organism that lives in (or on) a "host" organism and obtains a benefit without providing any benefits in return. For example, a worm that lives in a person is a parasite since worms confer no benefits. So are bacteria which are of no benefit and live in a person. Other parasites include viruses, protozoa and fungi (simple, non-green plants). For our purposes, the word "parasite" will be limited to worms, protozoa and certain insects all of which are animals.

Parasites commonly enter the digestive tract with food or water. Most of the dangers from such parasites have been reduced or eliminated in the U.S. by improved public health practices, but parasites are still a major problem in much of the rest of the world. For example, it is estimated that more than a third of the people in Asia, South America and Africa have worms.

Parasitic worms in the intestines seem to be well off--they are bathed by food that is already partly digested. And they themselves are protected from being digested by a thick, resistant outer coat called a cuticle.

Several parasitic diseases are caused by worms and protozoa. They may come from eating food containing the organisms or from putting contaminated food, drink or utensils into the mouth. Feces are one source of contamination, just as in hepatitis. Cysts may also be released into the environment from dead and decayed animals.

35-4 Tapeworms

How do tapeworms parasitize people?

The tapeworm is a parasite that must live in the intestines of man or another animal. It lacks the enzymes necessary to digest nutrients itself, so it lives in the intestines of its host and is surrounded by digested food which it absorbs.

Figure 2 depicts a tapeworm. On its head is a series of suckers. Some species have a ring of hooks too. The suckers and hooks allow a tapeworm to cling to the wall of its host's intestine, thereby preventing it from being carried along with the food moving through the intestine.

Below the head of the tapeworm is its neck. A series of flat, nearly square sections grow from the neck. These sections may extend the length of a tapeworm to as much as 30 feet. They contain the worm's reproductive organs. Eggs form in the sections, and as the eggs mature, the sections separate from the end of the tapeworm and are eliminated in the host's feces. This is how the eggs are spread.

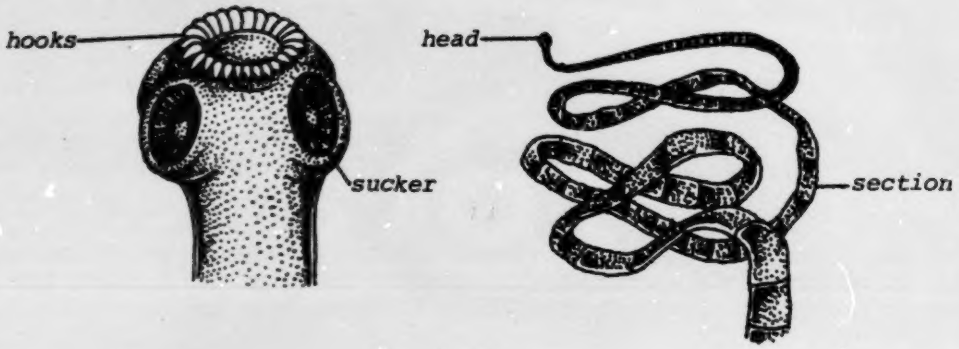


FIGURE 2: *A tapeworm.*

As with trichinosis, people get tapeworms by eating infected meat that is undercooked. Such meat--it may be beef, pork or fish--has tapeworm cysts. Each cyst contains a tapeworm head. In the human intestine, the head is released from the cyst and attaches to the intestine wall. Unlike *Trichinella,* most tapeworms do not migrate to the person's muscles; they remain in the intestines, sometimes for years.

Since tapeworms obtain their nourishment from their host, a person with this parasite may lose weight and vitality. The worm's presence may also irritate the gastrointestinal tract, causing pain and diarrhea. Diagnosis of a tapeworm infection depends on examining the feces of the patient for worm sections and eggs.

Treatment involves drugs to kill the tapeworm. It is necessary to remove the entire worm, because if the head is left attached to the intestine, the whole worm will grow larger again after two or three months. Most drugs are directed at killing the head. Once this is accomplished, the worm passes out with the feces.

Meat is regularly inspected for tapeworm cysts. Nevertheless, to be safe, beef and pork, and in some areas of the U.S., fish, must be cooked. Cooking throughout at 71 °C (160 °F) for at little as five minutes has been found to destroy cysts. Cysts are also destroyed by long periods of refrigeration and by salting.

35-5 Pinworms

How do people get pinworms?

Pinworms are probably the most common parasite afflicting humans. They reach their host from contaminated surfaces. These include utensils, hands, food, drink, etc. Children are particularly likely to get pinworm infection because they like to play in dirt and put their fingers and other objects into their mouths.

Pinworms look very different from tapeworms (Figure 3). People, usually children, get infected by ingesting the microscopic eggs.

A few hours after the egg is ingested it gives rise to a larva in the small intestine. Larvae grow into adults.

Within a month, adult female pinworms migrate to the anus. There they discharge their eggs onto the outer skin. This migration always occurs at night and produces the most noticeable symptom, which is itching of the skin around the anus.

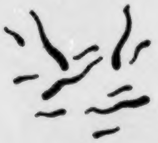


FIGURE 3: *Pinworms, actual size. The large pointed ones are females, the smaller ones males. Eggs are microscopic.*

Pinworm is so easily spread by bedding and towels--anything that touches the skin around the anus--that if one person in a family has it, it is typical to treat the entire family with drugs.

35-6 Amebic Dysentery

How do people get amebic dysentery?

An ameba is a tiny protozoan (Figure 4). An ameba has no front or back; in fact it has no permanent shape (Figure 4). It moves by pushing against its cell membrane, forming a projection called a pseudopod (Figure 4). The rest of the ameba follows behind. Repeated extension of pseudopods results in movement resembling crawling.

Pseudopods have a second use: they can engulf food particles (Figure 4). In this manner an ameba obtains nourishment.

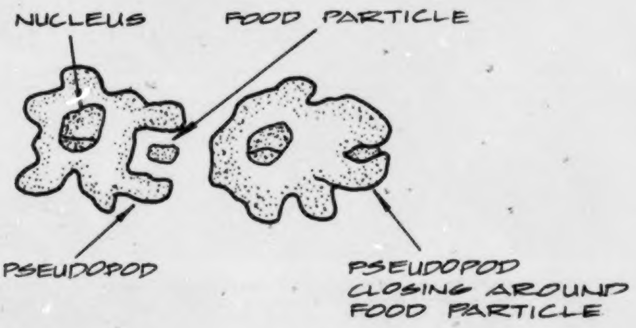


FIGURE 4: *Amebae, multiplied 1,000 times*

Sometimes, people who travel learn about an ameba the hard way, by contracting amebic dysentery. They contract this ameba by eating microscopic cysts. Cysts can enter the mouth on the fingers, or with food and water contaminated with infected feces. Even careful people sometimes get dysentery from brushing their teeth with contaminated water. Cysts are resistant to the acidic juices of the stomach and pass to the lower part of the small intestine. Here the cyst wall disintegrates and the amebae are released. If the amebae grow in the wall of the intestine they injure a portion of the intestinal lining, causing severe diarrhea.

Sometimes, an amebic infection is not noticed for weeks or months after beginning in the body. The person may become overtly ill long after returning home, with the diagnosis far from obvious. Drugs are used in treatment.

Amebic dysentery occurs throughout the world, but more frequently in tropical climates. It can be prevented by washing fruits, cooking vegetables, and either using uncontaminated water or, when in doubt, adding iodine capsules to the water or boiling it.

What is a parasite?

What effects does a tapeworm have on an infected individual? How are tapeworms eliminated from an infected person? How can we reduce our risk of ingesting tapeworm cysts?

What parasitic disease is characterized by the symptom of itching around the anus?

What causes amebic dysentery?

Vocabulary:

ameba (uh-MEE-buh)--a protozoan with an irregular, ever-changing shape.

cyst (sist)--the stage of the life cycle of certain organisms during which it is contained in a hard case. Under the right conditions, the cyst opens and the organism is released.

fungus (FUNG-gus)--simple plants that lack the pigment, chlorophyll, characteristic of green plants. The plural term is fungi (FUN-jye).

infested--containing disease organisms, usually said of food, water, clothing, or feces, when they contain the organisms.

larva (LAR-vuh)--the immature stage of certain animals such as insects. It is often smaller than the adult. Caterpillars are the larvae of butterflies.

life cycle--the stages of development of an organism.

parasite (PAR-uh-site)--a living thing that derives a benefit, such as food, from a host, without providing any benefit in return.

SECTION 36: WATER PURIFICATION

36-1 Controlling Bacteria in Drinking Water

How is drinking water kept free of harmful bacteria?

During the late 1800's water purification became common practice. Epidemics of bacterial diseases spread by contaminated water led to purification of drinking water by various means. But the water treatment plants that control dangerous bacteria today were not designed to control another factor that has become important in recent years: pollution by chemicals. We will consider this problem shortly, but first we will consider the steps taken to rid water of pathogenic (disease-causing) bacteria.

There are several ways to make sure water is safe. First water is subjected to purification at treatment plants. It is first allowed to sit in large tanks, often 100 or more feet across, so that particles, including some bacteria, will settle to the bottom. Then it is filtered through sand, which filters out 99 per cent of the remaining bacteria. Water treatment plants then add chlorine to kill still more bacteria. Secondly, in order to maintain the safety of water, public health officials make sure that treated water is not contaminated with feces. Recall that such waste products are a common source of disease.

It is generally impractical and unnecessary to sterilize our drinking water. Drinking water may be good even though it contains some non-pathogenic bacteria. Remember, your intestines are loaded with bacteria.

To make sure water is safe, drinking water is periodically tested for the presence of *Escherichia coli,* a bacterium found in feces. If these bacteria are present in the water in high amounts, it means the water has been contaminated by feces. In such an event there's a chance that pathogenic bacteria from the feces may also be present, and the water is declared unfit.

36-2 Chemicals in Drinking Water

Are there any links between drinking water and cancer?

While most communities have drinking water free from pathogenic bacteria, there are other problems. As a number of communities have recently learned, metals such as lead and mercury may be found in their drinking water. In farming regions the water often contains trace amounts of insecticides. It is possible for viruses to pass through community water treatment plants and cause outbreaks of disease, especially hepatitis. There is no monitoring process for viruses.

Thousands of years ago man could almost always count on a water supply free from toxic chemicals. As technological advances were made, the wastes of industry were discarded into the air and water. At the present time, water is considered safe for drinking if it won't cause typhoid, cholera, or other bacterial diseases. However, there are also industrial compounds that may enter our water system such as chloroform, benzene and ether, which may cause cancer. Not all of these compounds enter our water directly as waste products. Chloroform, for example, is formed as a result of chlorine reacting in the water. Water is not usually tested for these compounds, yet they have been found in the water in many communities. Of course, the amounts of these substances in the water are far less than the amounts that have been shown to produce cancer in experiments with animals, but it still brings into question their effects on people who drink small amounts daily for many years.

A study of the water supply of New Orleans, which comes from the Mississippi River, was conducted by the Federal Environmental Protection Agency (EPA). It revealed that several known cancer-producing agents were present. These chemical agents include insecticides, weed killers, coal tar, oil and other petroleum products as well as many other chemicals used in industry. These agents enter the Mississippi River from rainwater as it washes agricultural chemicals into streams and from accidental oil spills, as well as industrial wastes that are dumped directly into the river.

Finally, even pure water may have its hazards. While the evidence is conflicting, studies have indicated a possible link between mineral-free water and cardiovascular disease. As a result, some communities in Great Britain have stopped removing minerals from their water.

Name three bacterial diseases which can be transmitted by contaminated water.

How is water purified?

Name three chemical contaminants likely to appear in drinking water.

Why can't we say for certain that contaminated drinking water causes increased cancer death rates?

How can the amount of contaminants in our water be lowered?

Vocabulary

pathogenic (PATH-o-JEN-ik)--capable of causing disease; usually said of living things such as bacteria, viruses, etc.

SECTION 37: FOOD PROCESSING

37-1 Why is Food Processed?

Food processing is any treatment a food receives between being grown and being consumed. More than 95 per cent of our food is processed in one way or another. Processing affects the nutritional value of food, so we will devote this section to a study of food processing: why it is done, how it is done and what effect it has on the food we eat.

Food is processed for a number of reasons. Many foods are contaminated with either pests or pesticides, which must be removed to make the food safe to eat. Some foods are more appealing to consumers when processed. For example, most people prefer white sugar to raw sugar. A third reason to process food is to preserve it. Foods are often shipped long distances and stored for long periods of time. Canning, freezing, dehydrating, milling and simply wrapping are all done to preserve food until it is eaten.

People in the United States have come to rely more and more on packaged foods, because they are easier to prepare. People often select quick snacks and highly processed foods such as frozen dinners. Since processed foods have become so popular, it is important that we know the effects of processing on the nutrients in these foods.

37-2 Cereal Refining

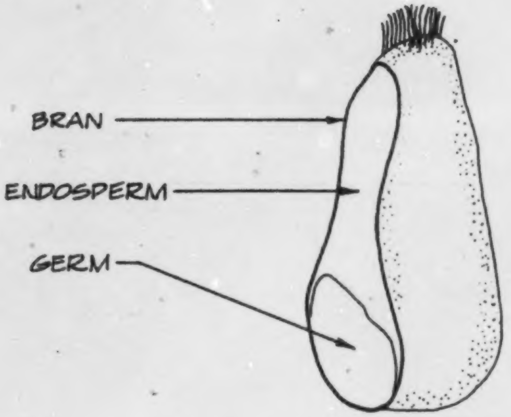
What happens to the nutritional value of grains when they are refined?

We get the word "cereal" from Ceres, the Roman goddess of agriculture, grains and the harvest. Cereals are not restricted to packaged breakfast foods, but incude all grains used as foods. The common cereal grains are rice, wheat, corn, oats, rye and barley.

Rice is the most frequently consumed grain, largely because of its importance in the diet of Asia. Corn is the most popular cereal in Latin America, while wheat is the most popular in the United States and western Europe.

A typical cereal grain is between 70 and 80 per cent carbohydrate, of which a small portion is indigestible cellulose. The protein content varies from 7.5 per cent to almost 15 per cent, and a grain may be as much as 1 per cent minerals. Grains are not important sources of vitamins A and C, but they can be good sources of B vitamins and iron.

The quantities of these nutrients that we actually receive from the grains in our diet depend upon how they are processed. To understand the processing of cereals, it is first necessary to know a little about the anatomy of a grain. A cross-section of a wheat grain is illustrated as an example, but the parts of other cereal grains are similar. A grain contains three types of cells, which may be separated during processing.



The outer layer of grain composes the bran. Bran cells have thick walls of the carbohydrate cellulose; these walls form a protective covering around the grain. The bran contains indigestible cellulose, but it also contains protein, iron and many B vitamins. The bran of a wheat grain contains most of the niacin and much of the riboflavin and thiamin. It is also an important source of roughage or fiber in our diets, and is essential to good digestion.

A second group of cells composes the germ. Germ cells are rich in polyunsaturated fatty acids and other nutrients. Fats in wheat germ are unstable, so the germ is commonly removed to prevent cereal products from spoiling or becoming rancid. (The oil from corn germ is used to make corn oil and margarine.) When the germ is discarded, polyunsaturated fatty acids are lost, along with most of the thiamin, and also some of the niacin, riboflavin, iron, protein and B vitamins pyridoxine and pantothenic acid.

The largest part of a grain is the endosperm. The endosperm contains three-fourths of the protein in a grain and much starch, but only small amounts of vitamins and minerals. For example, the endosperm of a wheat grain contains only 12 per cent of the niacin, 32 per cent of the riboflavin and 3 per cent of the thiamin.

White flour is made by grinding the endosperm of wheat. White flour itself contains inadequate amounts of several nutrients, but nutrients may be added. The addition of nutrients to a food is called fortification. A food may be fortified by adding a nutrient originally present but removed during processing, such as restoring vitamin C to frozen orange juice. Or it may be fortified by adding a nutrient not naturally present in the food, such as adding vitamin D to milk.

The Food and Drug Administration (FDA) has set standards for the addition of four nutrients to cereal products. If a flour or bread contains specified quantities of iron, niacin, riboflavin and thiamin, it is called "enriched." The standards of enrichment are generally such that an enriched product contains approximately the same amounts of these four nutrients as the unrefined grain does.

The following table compare the FDA standards for enriched wheat flour with the quantities present in whole-wheat and unenriched flour.

Nutrients in One Pound of Wheat Flours

	Iron mg	Niacin mg	Riboflavin mg	Thiamin mg
Whole Wheat	15	19.5	.54	2.50
Unenriched (white)	3.6	4.1	.23	.27
Enriched (white)	13 to 16.5	16 to 20	1.2 to 1.5	2 to 2.5

Note that enriched flour contains several times the quantities or iron, niacin, riboflavin and thiamin that unenriched flour does. Flour is often further enriched with calcium and vitamin D.

Enrichment restores iron, niacin, thiamin and riboflavin lost in processing, but FDA standards say nothing about other nutrients. Pyridoxine, pantothenic acid, vitamin E, phosphorus and magnesium are removed by milling but are not replaced by enrichment. Pyridoxine and pantothenic acid are as essential to health as the other B vitamins are, and an excess of one vitamin cannot compensate for the lack of another.

What is true of wheat is essentially true of rice also. The bran of a rice grain is surrounded by a hull, which is removed. Further milling or "polishing" removes the bran and germ leaving endosperm, or white rice.

Polished rice has an important place in the history of vitamins; you may recall the story from Section 20. Prisoners and chickens living on polished rice developed the nervous disorder beriberi. Chickens living on the portions of brown rice removed by milling did not develop berberi. This led to the conclusion that brown rice contains an ingredient removed during milling. The ingredient is thiamin; polished rice contains less than one-fourth the thiamin that brown rice does.

Unenriched rice is deficient in thiamin and other nutrients, but rice, like wheat, may be enriched. FDA standards for enriched rice specify that it contain quantities of thiamin, niacin, riboflavin and iron comparable to the quantities in unrefined rice.

Standards have also been set for enriching other grain products, such as cornmeal, macaroni and noodles. (If a food is enriched, it is so labeled.)

Over 90 per cent of the wheat flour and bread consumed in this country is enriched. No standards have been established, however, for enriching breakfast cereals. A few years ago a presidential consultant on hunger studied 60 popular dry breakfast cereals and stated that 40 were so low in nutrients as to be classed as "empty calories." Possibly as a result of publicity stemming from this study, many cereals are now being fortified with additional nutrients. Iron, niacin, riboflavin and thiamin are commonly added.

37-3 Canning, Freezing and Dehydration

What is the effect of canning, freezing and dehydration on the nutritional value of foods?

Before 1800 few foods could be preserved for more than a short period of time. During the 1790's the French government offered a prize for a method of preserving food for the army. Nicolas Appert experimented from 1795 to 1809. In 1810 he published a treatise entitled "The Book for All Households; or the Art of Preserving Animal and Vegetable Substances for Many Years." The treatise won Appert 12,000 francs (equivalent then to $2250), which was a lot of money in 1810.

Appert's experiments involved heating foods in sealed containers. Food was placed in bottles and stoppered with corks. The bottles were then heated in boiling water for several hours. In this way canning originated.

The principle behind canning was not understood, and little improvement was made in techniques until 60 years later when Louis Pasteur discovered that most food spoilage is caused by microorganisms. The high temperatures involved in canning destroy or make inactive the microorganisms that cause food to spoil. Canning also denatures any enzymes present in the food. This stops these enzymes from catalyzing reactions and prevents some undesirable changes in food. Sealing a container before heating prevents organisms from entering the food after it is sterilized.

Unfortunately, air-tight canning does not prevent growth of a bacterium called *Clostridium*. *Clostridium* is a kind of bacterium that lives best in the absence of oxygen. This organism causes a rare form of food-poisoning known as botulism. The toxin produced by this microbe is one of the most deadly poisons known. It has been estimated that as little as 10^{-7} g of this substance can kill an adult. Botulism occurred more frequently before it was found that this bacterium can be destroyed during the canning process by heating to temperatures near 100 °C for a certain period of time. But, this deadly form of food poisoning still occurs; especially in home-canned foods.

The obvious changes that occur when food is canned are changes in texture, color and flavor. Changes may also occur in nutrient content. Some proteins and vitamins can be destroyed by the heating needed to sterilize the food. Many foods must be scalded with

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hot water or steam before being canned; scalding serves a number of purposes such as enhancing the color of green vegetables and softening tissue to make packing easier. When scalding causes cell walls to break (for example, the skin of fruit) water-soluble vitamins may be lost. Many foods are packed in water or juice. If the water is poured off before the food is eaten, water-soluble vitamins and minerals are lost.

The table below includes a comparison of the nutrient content of fresh peas and canned peas, fresh peaches and canned peaches. The numbers include the nutrients contained in the water or juice in which the foods are packed, so if the juice is drained, the values are less.

FOOD	Protein (g)	Thiamin (mg)	Niacin (mg)	Riboflavin (mg)	Vitamin A (IU)	Vitamin C (mg)	Sodium (mg)	Calcium (mg)
100 g fresh peas	6.3	.35	2.9	.14	640	27	2	26
100 g canned peas	3.3	.09	.9	.05	450	9	236	20
100 g frozen peas	5.1	.27	1.7	.09	600	13	115	19
100 g fresh peaches	.6	.02	1.0	.05	1330	7	1	9
100 g canned (in juice)	.4	.01	.9	.04	670	4	2	6
100 g frozen peaches	.4	.01	.7	.04	650	41	2	4

Canned peas and peaches have somewhat lower quantities of nutrients that the fresh foods. Compare the amount of sodium in fresh peas and canned peas. Salt is added to many canned foods to improve taste and act as a preservative.

Foods may also be preserved by freezing. Freezing kills only a small percentage of bacteria, but surviving bacteria are unable to grow, and their enzymes are inactive, at freezing temperatures.

Frozen foods are generally closer to fresh foods in texture, appearance and taste than canned foods are (although certain foods cannot be frozen because of changes in texture, for example lettuce). In addition, frozen foods are often closer to fresh foods in nutrient content than canned foods are. The values for frozen peas and peaches are also included in the preceding table.

Vegetables are commonly scalded before freezing. This can cause denaturation of proteins and loss of water-soluble vitamins. Frozen peas contain less protein and less of each vitamin than fresh peas, but more than canned peas. Frozen peaches are comparable to canned peaches in every nutrient listed but vitamin C;

apparently the frozen peaches referred to in the food table were fortified with vitamin C. Less salt is usually added to frozen foods than to canned foods.

Freezing a food does not kill most bacteria but only inactivates them. When the food is thawed, the bacteria become active again and are able to grow. For this reason frozen foods should be cooked or eaten soon after they are thawed.

Dehydration is another method of preserving food. Dehydration is the removal of all, or at least most, of the water from a food. The absence of water does not kill all the bacteria but causes the remainder to be inactive until the food is reconstituted with water.

We cannot provide extensive nutritional information on freeze-dried foods, but to compare a dehydrated food to a food before being dehydrated, the following table gives the nutrient content of one cup of nonfat milk and one cup of milk made from nonfat dry solids.

FOOD	Protein (g)	Thiamin (mg)	Niacin (mg)	Riboflavin (mg)	Vitamin A (IU)	Vitamin C (mg)	Sodium (mg)	Calcium (mg)
1 cup nonfat milk	8.8	.10	.2	.44	0	2	128	298
1 cup milk made from nonfat dry solids	7.1	.07	.2	.35	6	1	105	259

Milk made from nonfat dry solids contains almost the same quantities of nutrients listed as nonfat milk does.

Dehydration is one of the oldest methods of preserving foods (consider raisins, jerked meat, and smoked fish.) The development of modern techniques for drying foods, such as freeze-drying, got its impetus from the Army's need for food with minimum mass and volume. Such lightweight foods are now associated with activities like backpacking.

Water boils at a lower temperature and evaporates more readily when the pressure is low. Freeze-drying takes advantage of this fact. A food is frozen and subjected to vacuum pressure which causes the frozen water to evaporate. The product is generally different from that obtained by the process of dehydration by heating, and many foods that cannot be satisfactorily dried by heating can be dried while frozen under low pressure.

Which part of a wheat grain is used to make white flour and white bread?

Why should the other two parts of the grain not be removed?

What nutrients are added when flour is enriched?

What nutrients present in whole-wheat flour are not added to enriched flour?

Why does canning preserve food? How does freezing preserve food? How does dehydration preserve food?

Which nutrient do canned vegetables contain more of than fresh vegetables?

How are nutrients lost during canning?

Vocabulary

bran--the outer layer of cereals; rich source of vitamins, iron, protein and fiber.

endosperm (EN-doe-SPERM)--the largest part of a cereal grain; rich in starch and protein but poor in vitamins and minerals.

fortification--the addition of nutrients to a food.

freeze-drying--a method of removing water under vacuum while a substance is frozen.

germ--the innermost layer of a cereal grain; rich in unsaturated fatty acids, vitamins, minerals and protein.

SECTION 38: FOOD ADDITIVES AND HEALTH

38-1 Food Additives

Do you know what gum arabic is? Would you eat it?

Chances are that you consume gum arabic frequently, although you may not know what it is or what it does to your body. Gum arabic, also known as gum acacia, is added to many of the easily prepared food products, such as cereals, prepared dinners, and powdered beverage mixes. Gum arabic is obtained from an acacia tree of Africa and Arabia; it is tasteless, odorless and soluble in water. Cellulose gum, guar gum and agar-agar are also added to many of these foods. Why? That is one of the subjects of this section, in which we will discuss the various uses of food additives. We will also be concerned about possible health problems linked to food additives. While the term "foodborne disease" is generally used to refer only to those diseases caused by microorganisms, we must not overlook the possibility that many food additives may also affect our health.

An additive is a substance added to a food during processing or preparation. The substance may not have been present in the food as it occurs naturally, or it may have been present in a lesser amount than in the product. Thus, when milk is fortified with vitamin D, we consider the vitamin to be an additive, because it is not naturally present in milk. Similarly, when vitamin C (ascorbic acid) is added to processed orange juice, this vitamin is also considered an additive even though vitamin C was in the original juice.

When we consider an artificially created food product, however, there is no exact distinction between a food and an additive. Take, for example, a list of ingredients in ice cream. A typical list may include milk, cream, sucrose, nonfat solids, corn syrup, artificial color, artificial flavor, stabilizer and emulsifier. We would probably agree that milk and cream are foods and that artificial color and flavor are additives. But what about sucrose? Whether sugar is an additive or not can be debated, but it does not matter. What does matter is the effect of sucrose on the taste of ice cream and its effect on the health of those who eat ice cream.

There are many reasons why substances are added to foods. An additive may make a food more nutritious. For example, flour and bread may be enriched by the addition of vitamins and iron. Milk may be fortified with vitamin D; ascorbic acid may be added to synthetic orange beverages.

Other additives are used to preserve food. For example, sodium propionate and calcium propionate are commonly added to bread and other baked foods to retard the growth of molds (fungi).

Two other common preservatives are butylated hydroxytoluene, commonly called BHT, and butylated hydroxyanisole, or BHA. Fats tend to oxidize and become rancid. BHT and BHA retard oxidation and are added to many foods that contain fats, one example being salad oils.

Most additives are used to make a food more appealing to the consumer. Food can be made more appealing by improving its flavor, texture or color. The ingredients of ice cream, listed previously in this section, illustrate the use of additives to improve flavor, color and texture. The list includes artificial color, artificial flavor, corn syrup, stabilizer and emulsifier. Let's examine each of these additives.

Artificial flavor and color explain themselves. Flavors are the largest group of food additives; over 1000 are available. Spices were among the earliest additives used to improve the flavor of food; spices are naturally occurring substances. New synthetic flavors are developed each year, to imitate natural fruit flavors, for example.

Corn syrup is added to ice cream as a sweetener and also to prevent sugar from crystallizing; it thus improves both taste and texture. Stabilizers and emulsifiers, as well as thickening agents, are added to food to improve its texture. A stabilizer in ice cream helps to keep the rest of the ingredients mixed and prevents large ice crystals from forming when ice cream is frozen.

Gum arabic and other vegetable gums are used as stabilizers and thickeners. They may be added to ice cream, and they also are commonly added to such foods as powdered beverage mixes and hot breakfast cereals to obtain the proper texture when these foods are mixed with water.

When you analyzed a food for its nutrient content, you found that fat is not soluble in water. In many foods such as ice cream, fat would separate from water and water-soluble ingredients were it not for the presence of an emulsifier. An emulsifier causes fat to be dispersed in small droplets throughout the water-soluble portion. (You may recall that bile served as an emulsifier for fats being digested in the intestines.)

There are still other reasons that manufacturers add substances to food. For example, certain additives change the pH of a food. Others control the moisture content. How do all these additives we consume affect our health?

Man has lived with many of his foods for thousands of years. Centuries of use have indicated that these foods are not harmful, or at least not immediately harmful. Consumption of a food by 100 generations of people is a very good test, but there remain problems and uncertainties. Foods long considered harmless may be harmful indirectly and over a long period of time, or when excessive quantities are eaten. For example, both salt and sugar are not as harmless as had long been supposed. The other problem is additives developed recently--ones that have not been tested for long periods of time. How are these additives determined to be safe?

In the United States the Food and Drug Administration is responsible for seeing that the approximately 2000 food additives are not harmful. The FDA's task is not easy for reasons we will discuss.

The FDA derives its authority to control the use of additives from the Food Additives Amendment to the Federal Food, Drug and Cosmetic Act of 1958. Before 1958, if the FDA wished to remove a particular additive from the market, it had to demonstrate that the additive was harmful. Since the passage of the act, a manufacturer has to satisfy the FDA that a new additive is not harmful before it may be used.

The Food Additives Amendment contains a list of additives that are "Generally Recognized As Safe, (GRAS)." The approximately 670 substances in this list, known as the GRAS list, either have a long history of use or were proven to be harmless prior to 1953. The GRAS list includes nutrients (for example, riboflavin), such flavors as cinnamon and vanilla, salt and pepper, and additives to improve texture, such as gum arabic.

The fact that a substance is on the GRAS list means nothing more than that it is "generally recognized as safe." Many of these additives have never been proven to be safe, and the FDA can remove a substance from the GRAS list if evidence appears against it. At present the FDA is testing or re-testing each additive on the GRAS list for toxicity.

If a new additive is developed, it must be approved by the FDA before it may be used in food. The manufacturer must test the additive with at least two species of laboratory animals, commonly mice and dogs. The animals are fed various quantities of the additive, and the smallest quantity that is harmful is determined.

The FDA regulates not only what additives may be used, but also in what foods they may be used and how much may be used. The decision as to how much of an additive may be used in a certain food is based upon the tests with laboratory animals, and it takes into consideration whether a person is likely to consume the additive only in the one food or in other foods in his diet. The FDA is also guided by the principle that a food should contain no more of an additive than is needed to achieve its purpose.

The FDA also considers the purpose of an additive. Additives are permitted for the purposes we mentioned: to improve the nutritional value of a food, to aid in preservation of food and to improve color, flavor or texture. Additives are not permitted, however, to disguise inferior food or inferior processing.

One clause of the Food Additives Amendment specifically bans any additive that is found to be associated with cancer in laboratory animals or people. This statement, called the Delaney clause after the congressman who introduced it, was the cause of controversy in the case of cyclamates. Cyclamates were on the GRAS list and were used as artificial sweeteners in place of sugar. Their most popular use was in diet sodas. Cyclamates are probably preferable to sugar in terms of dental health, losing weight, and risk of atherosclerosis; they made some foods suitable for diabetics that were not otherwise available to them. However, it was determined that rats fed huge quantities of cyclamates tended to develop cancer. Although the quantities were much greater than are ever consumed by a person, cyclamates were ordered off the market. Cyclamates are one example of the problems encountered by the FDA. Another problem is the use of nitrates and nitrites.

38-2 Nitrates and Nitrites

A nitrate is a compound containing the nitrate ion NO_3^-. An example of a nitrate is sodium nitrate, $NaNO_3$. Nitrites are compounds containing the nitrite ion, which is NO_2^-, for example, $NaNO_2$, sodium nitrite. Nitrates and nitrites are considered together because under certain conditions a nitrate converts to a nitrite, and nitrites are at the center of the problem.

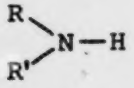
Nitrates occur naturally in many water supplies. They also occur naturally in many vegetables, notably spinach, beets, lettuce and eggplant. And sodium nitrate and potassium nitrate, as well as the nitrites, are used in curing meat products. Meat is cured by soaking in a brine (salt water) containing nitrates or nitrites. The primary purpose of adding nitrates and nitrites to meat is to preserve the characteristic red color of such meats as ham, bacon and frankfurters. Nitrates and nitrites also contribute to the flavor of these meats as well as that of cured fish. These additives also serve the useful function of inhibiting the growth of certain kinds of bacteria, such as the one which causes botulism.

Nitrates have not been found to be harmful in themselves, but as mentioned earlier, nitrates can convert to nitrites. One set of conditions under which nitrates can form nitrites occurs in the digestive tract of cattle; another is in infants' stomachs, which are less acidic than the stomachs of adults.

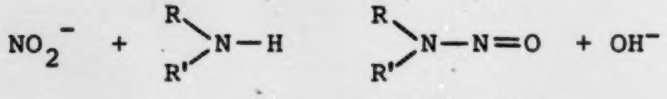
Nitrites have been proven to cause one medical problem and are suspected of causing a second. A nitrite can react with hemoglobin. You may recall the role of hemoglobin in transporting oxygen in the blood. When nitrite is present in the blood, hemoglobin is changed so that it cannot transport oxygen. Cases have occurred in which cattle have consumed too much nitrate, converted it to nitrite and have been poisoned in this way.

More concern has been shown for the possibility that nitrites lead to cancer. Let us examine some of the evidence.

We have already discussed primary amines (R-NH_2). Secondary amines have a second "R" group. They have the general formula



Under the right conditions a nitrite reacts with a secondary amine to form a nitrosamine.



nitrosamine

The reason for our interest in this reaction is that many nitrosamines have been found to cause cancer. If a substance causes cancer, it is said to be carcinogenic; thus many nitrosamines are carcinogenic. We must explain our use of the word "cause." The precise cause of cancer is not known, but it is known that laboratory animals that are fed nitrosamines develop cancer far more frequently than others that are not given nitrosamines. In addition, a combination of nitrites and secondary amines is equally carcinogenic in rats and mice. Significantly, though, the occurrence of cancer is not higher than normal when mice and rats are given nitrites but not amines. What does this mean in terms of man? Do nitrites and nitrosamines cause cancer in humans?

First of all, no case of cancer in a human has yet been proven to be caused by these substances. However, based on the experiments with laboratory animals, and the biological similarity of these animals to humans, it is reasonable to expect that nitrosamines can cause cancer in humans.

The next question is whether we consume nitrosamines or produce them within our bodies. Analysis of foods has indicated only very small quantities of nitrosamines in a few foods. However only a limited number of foods have been analyzed for nitrosamines, and the first part of the question remains unanswered. (Recent research, however, has indicated that cigarette smoke contains nitrosamines. This, of course, has caused further speculation about the carcinogenic nature of cigarettes.)

We already mentioned that rats do not develop cancer when fed nitrites alone; it is the combination of nitrites and secondary amines that appears to be carcinogenic. It is possible for us to have secondary amines in our bodies; for example, many drugs contain secondary amines. But the reaction of nitrites and amines can take place only under certain conditions. Are the conditions present in our bodies? This question remains unanswered. We do not yet know whether nitrites and secondary amines can react in our bodies.

If you were asked to decide about the use of nitrates and nitrites as food additives, what would be your decision? Remember that nitrites also inhibit the growth of toxic bacteria. If nitrates and nitrites were not used as additives, other preservatives would have to be used, or fresh foods used to replace preserved varieties.

Some people are advocating a ban on nitrates and nitrites as food additives. Some supermarkets already stock such meats as frankfurters which do not contain either preservative. As a result, such hot dogs have to be cooked and eaten within about one week of manufacture. But this is advantageous to the consumer who gets much fresher meat. By contrast, with nitrates and nitrites, meat can be preserved for very long periods. Consequently, there is no sure way to determine the age of meats such as hot dogs, salami, bologna, bacon and Vienna sausage.

Those calling for a ban on these preservatives seem closer to the intent of the FDA law than those who suggest we use nitrites and nitrates until it can be proven that they cause cancer in humans. Remember that the FDA regulation of 1958 requires that the food processors prove that these chemicals (or any food additives) are harmless before they use them in our foods.

List five uses of food additives.

What is the GRAS list?

What is the Delaney clause?

What are nitrates and nitrites used for?

Why do some scientists suggest that these food chemicals be banned?

If you were a farmer or food processor, what arguments might you give for retaining these food additives?

Vocabulary:

carcinogenic (CAR-sin-oh-JEN-ik)--cancer causing.

cured--treated with various compounds or processes (such as salt or smoke) for the purpose of preservation.

SECTION 39: READING FOOD LABELS

39-1 Why Read Labels?

One of the key points of the Nutrition Unit is that an optimal diet can be designed, and that we can determine how to eat for health and vitality. It does not take a medical degree or any other advanced degree to do this. In fact, you have already devised an optimal diet for yourself. But to continue to do so, long after this unit has been completed you will have to know to interpret the information given by food labels.

In the case of fresh, unpackaged foods the various books and tables you encountered in previous sections (see USDA Bulletin 72, and Bowes and Church) will tell you which nutrients are present and in what amounts. Packaged food is even easier to evaluate for gross nutritional information. This is because the nutrition panel on a food package lists how many calories and how much protein, carbohydrates and fat a serving of that food will provide. It also shows the percentage of the U.S. Recommended Daily Allowance (RDA) of protein and seven essential vitamins and minerals provided by a serving. All of this information is required by federal law. At the option of the manufacturer the label may also list how much polyunsaturated and saturated fatty acids, cholesterol and sodium the food contains, and may also list the percentage of the RDA for another dozen minerals and vitamins.

In addition to nutrition information, labels tell us which additives, if any, are present in packaged food. This is very important, as seen in the last section. While some additives are useful, others are of questionable safety yet find their way into foods.

39-2 How Do You Read a Label?

The first category of information to look for is the list of ingredients. A food may be nutritionally sound but not to our taste, unless it contains the kinds of nutrients we like to eat.

Ingredients are listed in order of the amount that is present--labels read from most to least. For example, looking at the nutrition panel of a can of fruit cocktail, you might learn at once that there are more peaches than pears (since peaches are listed first), more pears than grapes, more grapes than pineapple, and more pineapple than cherries. You would also learn that the syrup contains more water than sugar.

You may also want to read the label on a package of raspberry gelatin. From the picture of rosy-red raspberries, it would be reasonable to assume that the powder inside is made from natural raspberries. However, the label shows us that the powder is made of sugar, gelatin, fumaric acid, sodium citrate, salt, artificial flavor and artificial colors, but not raspberries.

39-3 Reading Labels for Nutrients

In addition to ingredients, you may want to know which nutrients are present in a packaged food (see Figure 1).

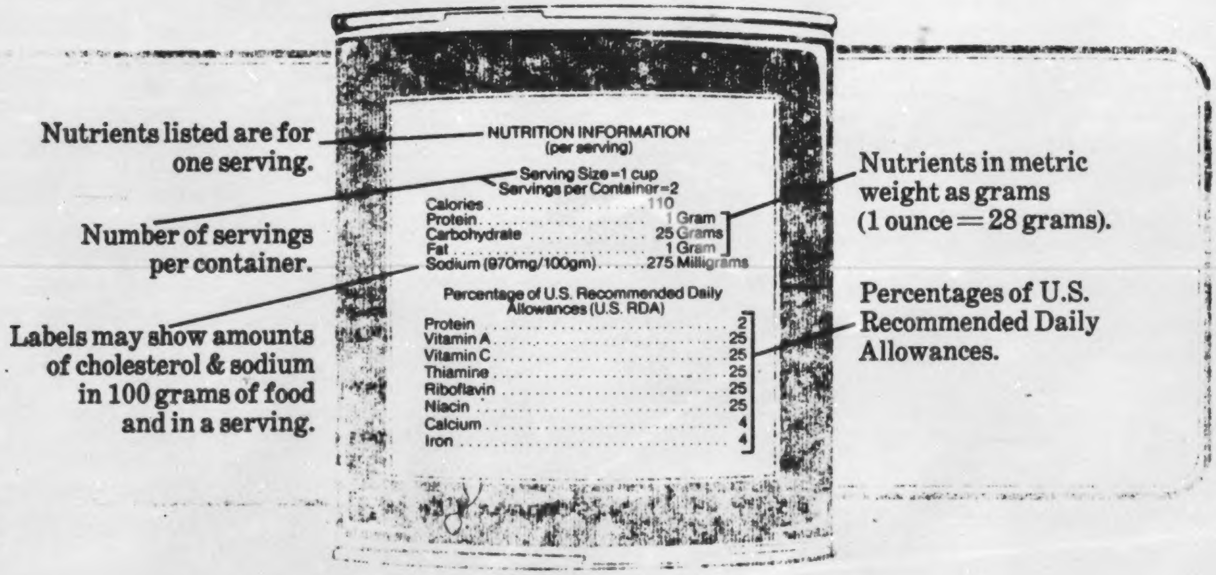

Nutrients listed are for one serving.
Number of servings per container.
Labels may show amounts of cholesterol & sodium in 100 grams of food and in a serving.
NUTRITION INFORMATION
(per serving)
Serving Size = 1 cup
Servings per Container = 2
Calories 110
Protein 1 Gram
Carbohydrate 25 Grams
Fat 1 Gram
Sodium (970mg/100gm) 275 Milligrams
Percentage of U.S. Recommended Daily Allowances (U.S. RDA)
Protein 2
Vitamin A 25
Vitamin C 25
Thiamine 25
Riboflavin 25
Niacin 25
Calcium 4
Iron 4
Nutrients in metric weight as grams (1 ounce = 28 grams).
Percentages of U.S. Recommended Daily Allowances.

FIGURE 1: *A typical food label.*

The upper portion of the label shows the number of calories in a serving of the food and lists, in grams, the amount of protein, carbohydrate and fat. These are three of the major nutrients that make up all the food we eat.

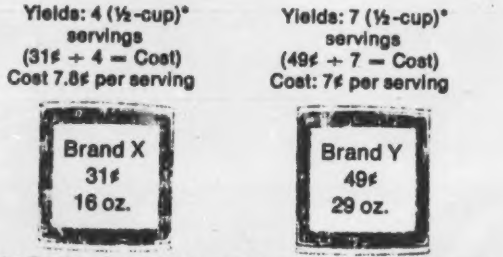
The lower portion of the label gives the percentage of U.S. Recommended Daily Allowance for protein and seven vitamins and minerals provided in one serving. Add percentages for each nutrient consumed throughout the day. When the daily total approaches 100, you are getting an ample supply of that nutrient.

Certain food products (in addition to butter, cheese and ice cream) are not required to give nutritional information. These include foods shipped in bulk for use in the manufacture of other foods, and foods supplied for institutional food service. This means that dinners eaten in cafeterias, on airplanes, in trains and other "institutions" may contain packaged food items, such as salad dressing, which do not provide an indication of what they are made of.

39-4 Reading Labels and Economy

How can you save money by reading labels?

To buy food economically there are other considerations (see Figure 2).



*Note: Serving sizes must be the same for accurate comparison.

FIGURE 2: *Comparison of two brands.*

To save money, (1) use labels to compare the cost per serving of similar foods, and (2) read labels to make sure you get the most for your food dollar. For example, compare two frozen pot pies of the same weight. One costs 39 cents, the other 29 cents. But when you read the nutrition label, you may see that the pot pie which costs 39 cents provides a higher percentage of the RDA for protein. So if you are serving the pot pie as a main dish and protein content is important, the one that costs 39 cents may be a better buy nutritionally.

39-5 Reading Labels for Additives

When reading labels, a careful consumer should be concerned about the additives included and what effects they may have on him. While there are too many additives used to allow a complete discussion of them, a number of common additives will be explored in Laboratory Activity 39. The list of unquestionably safe additives is very short, while the possible danger from those which are questionable or potentially harmful remains great.

There is no agreement among experts on the safety of one group of additives: the artificial colors. While some of these food dyes are "certified" as safe in the United States, they are not permitted in foods in many European countries. Conversely, some dyes considered absolutely safe abroad may not be used in this country. With so little agreement about the relative safety of the artificial colors the best rule of thumb may be to be extremely wary of them.

One example of an artificial color of known danger that is permitted is the red color used to dye maraschino cherries. Many of us eat these shiny cherries in ice cream, fruit desserts, cakes and pastries. Yet the dye that gives these cherries their color was outlawed for use in foods in 1964 because experiments with dogs produced two forms of cancer. When this artificial color was added as two per cent of their diets (a large amount--far more than any of us would consume), 60 per cent of the test dogs died. This dye is so harmful that the World Health Organization (WHO) gave in their lowest rating. According to this organization, this means it should not be used in food under any circumstance.

While the dye used in maraschino cherries is not used in any other foods, some other artificial colors are also of questionable safety. Fortunately, almost all foods using artificial coloring must state so clearly, on the label. Yet there are exceptions. Butter, cheese and ice cream may contain artificial coloring without having to show this on the labels.

What information is provided by labels on packaged food?

How can you tell which ingredient listed in a food label is present in the highest percentage?

How can you save money by reading labels?

Name two food additives of questionable safety.

Name three types of food exempt from the nutrition labeling laws.

REVIEW SET 39:

1. Name two general types of contaminants found in some water.

2. List two useful functions of bacteria found inside our digestive tract.

3. What causes trichinosis? How may we reduce our risk of contracting this disease?

4. Name at least three types of parasites which cause disease.

5. How are bacteria removed from drinking water?

6. Name at least two organic chemicals sometimes found in drinking water.

7. How can we reduce our intake of food preservatives?

8. Why is there concern about the possible dangers of sodium nitrate, and sodium nitrite--common meat preservatives?

9. In what ways is food-labeling information useful?

10. Why is food processed?

11. What is a food additive? Name three common food additives and their uses.

SECTION 40: THE ROLE OF TEETH IN NUTRITION

How do teeth prepare food for digestion?

Some of the most common health problems involve the teeth and gums--probably all of you have experienced at least occasional dental problems. Over 90 per cent of our population has at least one cavity in a life time. Over 10% of the adult population no longer has any natural teeth. More than half of the adult population suffer from gum diseases. Beginning in this section we will examine the teeth, their anatomy and function, as well as their problems and care.

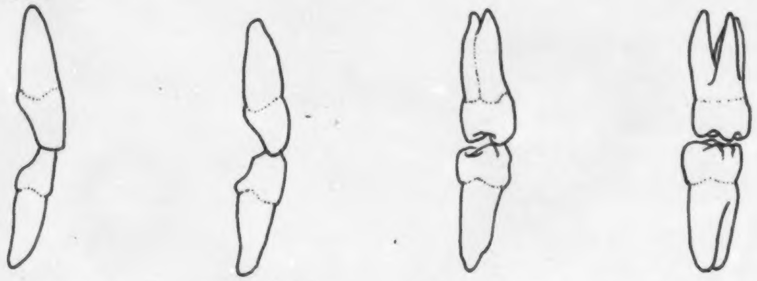
The science of Dentistry has developed to care for the teeth. Many occupations are concerned with human dentition. These occupations include dentist, oral surgeon, dental hygientist, dental assistant, dental X-ray technician and other technicians who specialize in making dentures, bridges and other dental apparatus.

As we have discussed, digestion begins in the mouth. Food is broken into smaller pieces by the teeth, and digestion of starch is begun by the enzyme amylase found in saliva. The function of teeth is important because small particles are digested more rapidly than large particles. They can come in closer contact with enzymes. The tongue helps mix food and moves it to where it can be chewed by the teeth.

The tongue is not only involved in moving food, but it has two other functions, taste and speech. The palate is also used for taste and speech. The palate is the roof of the mouth within the semi-circle of the upper teeth. The forward part of the roof is the hard palate; the rear portion is the soft palate. At the rear of the palate, a small flap of tissue called the uvula hangs down into the mouth. You can see your palate and uvula with a mirror. During swallowing, the uvula closes off the mouth from the nasal passage.

The mouth of a human adult contains 32 teeth, unless some have been removed. These teeth are not all alike; there are four types, each adapted to a different function. Before reading on, you might look at your teeth in a mirror. Can you detect four different basic shapes. Can you guess how these different shapes might function?

The four forward teeth on top and the four on the bottom are incisors (see Figure 1). Those in the center are central incisors, while those to the side are lateral incisors. Each incisor has a single root. Incisors have a thin edge and their function is to cut food.



incisors **cuspids** **bicuspids** **molars**

FIGURE 1: *The four kinds of teeth.*

To either side of the incisors are cuspids. Cuspids are the pointed teeth sometimes called canine teeth because of their resemblance to fangs (the word "canine" comes from the Latin word for dog). The mouth contains four cuspids, one on each side of the top and one on each side of the bottom. The function of the cuspids is to tear food. A cuspid, like an incisor, has one root.

Behind the cuspids are bicuspids. Bicuspids are so called because they have two points or cusps on their cutting surfaces. On each side, top and bottom, are two bicuspids, making a total of eight in an adult mouth. Bicuspids may have one or two roots. The function of bicuspids is to cut and tear and also to grind.

The teeth toward the rear of the mouth, behind the bicuspids, are molars. If you have all four of your wisdom teeth, then you have three molars on each side on top and three on each side of the bottom. Molars have either a double or a triple root. They are the largest teeth in the mouth and have large, uneven surfaces. Their function is to crush and grind food. The points on the surface grasp food as it is being ground.

Observe the relation between the shape of a tooth and its function. A cuspid, which is pointed, cannot grind food but is used to tear food. A molar, however, has a large irregular surface that is used for grinding rather than tearing. An incisor has an edge and is used for cutting. The shape of a bicuspid is intermediate between the shapes of a cuspid and a molar, and it is used both for tearing and grinding.

Chewing is a habit for most people. Consequently you are not likely to know how you chew certain foods. If a smaller piece of food must be separated from a large piece you usually bite off the piece with your incisors. This is the way you bite a piece from a whole carrot or from a chicken leg. If you cut meat with a knife, however, or place food on your tongue with a spoon or fork, incisors are not used. Whether incisors are used or not, food is moved progressively toward your rear teeth with the help of your tongue. The piece cut off by the incisors or placed on the tongue by a fork is separated into smaller pieces by the cuspids and bicuspids. It is finally crushed or ground by the molars and is then ready to be swallowed. Next time you eat a meal, you might review the different roles of your teeth.

A tooth is composed of several parts (see Figure 2). The part of the tooth above the gum is the crown. The outer layer of the crown is the hard, white substance enamel. The enamel consists of inorganic crystals of calcium phosphate. The crown has no blood supply.

The tooth narrows where it meets the gum; this section is called the neck. The portion of the tooth beneath the gum is the root. The root is anchored to the jaw by the periodontal membrane. The outer layer of the root is called the cementum. Cementum is softer than enamel and therefore decays more easily than enamel.

Beneath the enamel and cementum is the dentin. Dentin is softer and more porous than enamel. Although it has no blood vessels, it does contain organic fibers. The dentin surrounds the soft pulp cavity, which is where nerves and blood vessels are located.

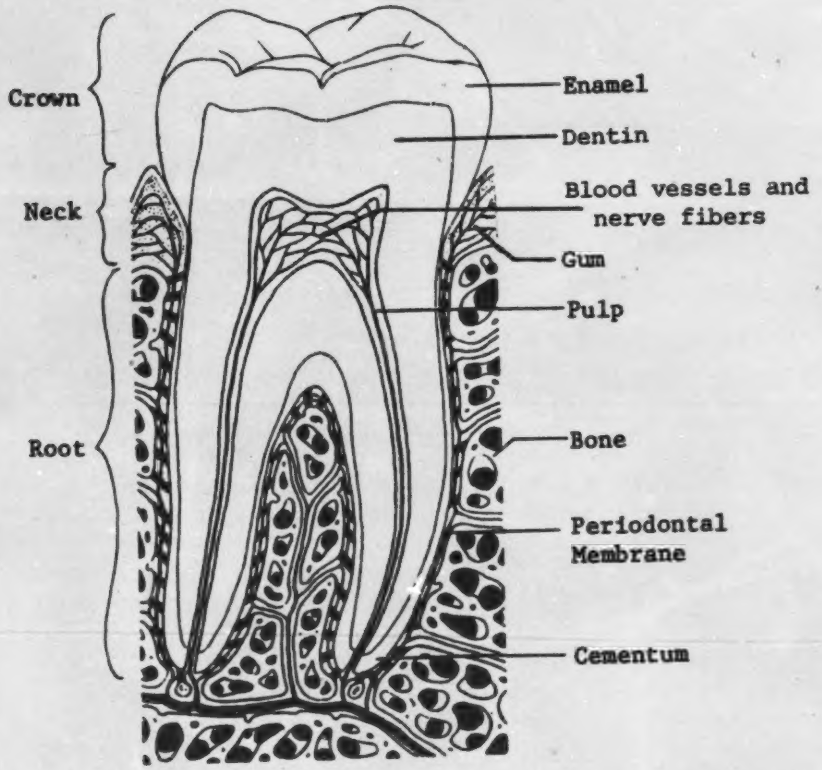


FIGURE 2: *The parts of a tooth.*

The outer parts of a tooth, the enamel and the cementum, have an interesting development before birth. During the early part of their development they are in contact with the body through nerves and blood vessels. However, at the time a tooth erupts through the gums, the blood supply and nerve connections to the outer part of the tooth are severed. Enamel and cementum are unlike bone in that they have no ability to repair either injury or decay.

What functions do the teeth perform that make them an important part of our anatomy?

What are the four different kinds of teeth?

In what ways are the teeth specialized for chewing?

Why do dogs need large canine teeth?

Classify the structure of the teeth as hard or soft. Consider enamel, cementum, dentin and pulp.

Vocabulary:

bicuspid (by-KUS-pid)--the teeth between the cuspids and the molars.

cementum (seh-MEN-tum)--the bony tissue which is the outer layer of the root.

crown--the part of a tooth above the gum.

cuspid (KUS-pid)--the fang-like teeth next to the incisors; the canine teeth.

dentin--the bone-like tissue just beneath the enamel and cementum in a tooth.

enamel--the hard white outer layer of the crown.

incisor (in-SY-zor)--the four top and four bottom front teeth, with thin cutting edges.

molars (MO-larz)--the largest teeth, in the rear of the mouth, with large uneven surfaces for grinding.

palate--the roof of the mouth, within the semicircle of the upper teeth.

pulp--the soft tissue deep in the tooth, containing blood vessels and nerves.

root--the part of a tooth below the gum.

SECTION 41: THE DEVELOPMENT OF TEETH

41-1 How Do Human Teeth Develop?

Proper development is essential to good dental health. The formation of teeth begins long before birth. When a fetus (human embryo) has been developing for five months, the central incisors and other teeth begin to form. Layers of enamel and dentin deposit and form the future crown, but they are below the gums (Figure 1).

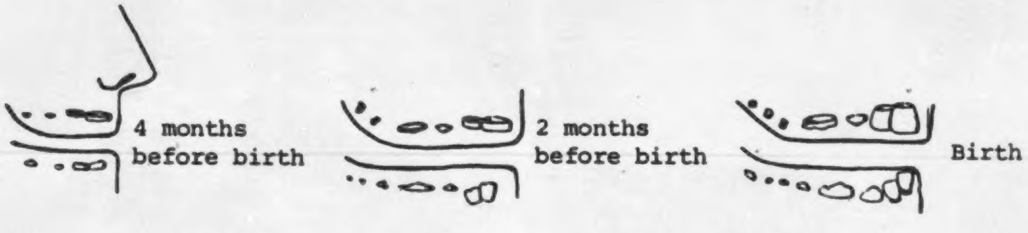


FIGURE 1: *Development of teeth until birth.*

Development continues, but at birth no teeth have erupted; in fact, roots have not yet formed. (A very few cases are reported in which a baby is born with an incisor; usually the baby was overdue.) Cuspids, bicuspids and molars all begin to form before birth.

When an infant is about six months old, his lower central incisors begin to erupt and there is typically excitement in the household. The lower central incisors are soon followed by the upper central incisors. During the next 18 months lateral incisors, cuspids and bicuspids complete their development and erupt. A child at the age of two years has the same number of these types as an adult has: eight incisors, four cuspids and eight baby molars. (See Figure 2.)

The 20 teeth in the mouth of a two-year-old child, however, are not the teeth he will have as an adult. They are called deciduous teeth or, commonly, "baby" teeth, and will be replaced by larger permanent teeth.

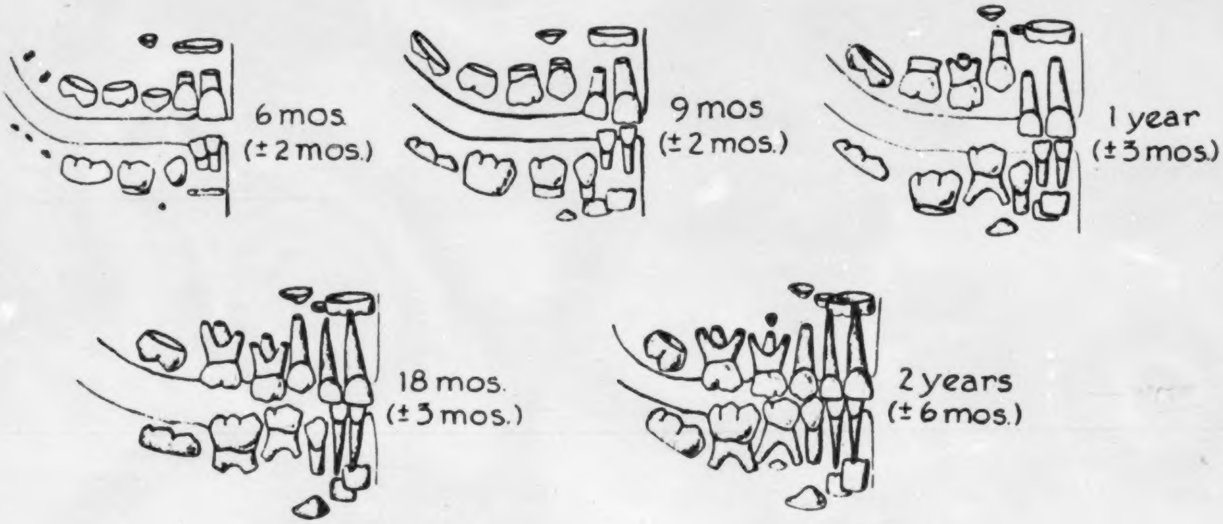


FIGURE 2: *Early development of teeth after birth.*

The period between the ages of six months and two years is a difficult time for an infant. The eruption of deciduous teeth is painful. And the digestive system is becoming adjusted to a new diet. Nutritional upsets are common at this age and can affect development of the permanent teeth. The crowns of these teeth are forming, and the nutritional disturbances can cause improper hardening of the enamel. These defects cannot be corrected once they exist; this is one reason that good nutrition is especially important during the first two years of life.

Between the ages of two years and six years, the permanent teeth continue to develop. Beginning at about the age of two all the deciduous teeth are in the mouth. At around five years of age the deciduous teeth become spaced. This happens because the jaw is growing larger. This spacing makes room for the permanent teeth that soon will erupt (Figure 3.)

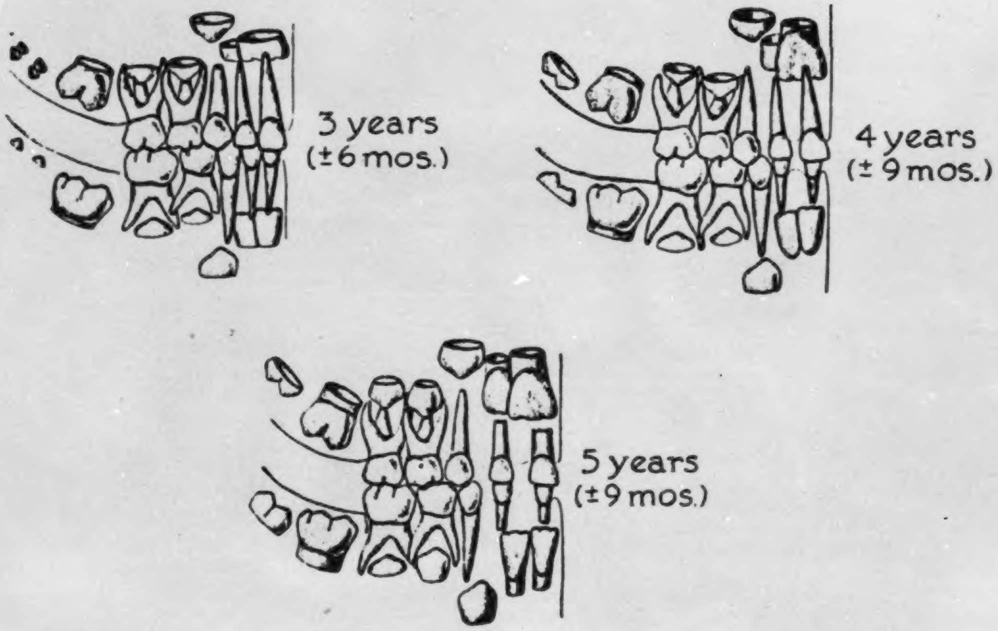


FIGURE 3: *Development of teeth from ages three through five.*

As the child approaches the age of six, the roots of his deciduous teeth begin to disappear. The process is called resorption; the material of the roots is absorbed into the body. This process leads to loss of deciduous teeth. When the root has been resorbed, the tooth is no longer anchored to the jaw and falls out. If the child places this tooth beneath his pillow, hopefully he is visited by the tooth fairy.

The period from the ages of six to ten is called the period of mixed dentition, because the mouth contains a mixture of deciduous and permanent teeth. The first set of permanent molars erupts at about the age of six. These molars are often presumed by parents to be deciduous and allowed to decay, since it is thought that they will be replaced by permanent molars. However, this is not true; the molars which erupt at the age of six are permanent teeth. Permitting these molars to decay can lead to more serious problems, because they are important in determining the positions of the other teeth (Figure 4).

Permanent incisors do not usually erupt in perfect alignment, but are spaced. The condition is corrected, though, by eruption of the cuspids, which pushes the incisors together.

The first bicuspids erupt at about age eleven. Because they erupt before the teeth to either side, they are important in guiding the cuspids and second bicuspids into position. The cuspids and second bicuspids usually erupt before the age of 12 (Figure 4).

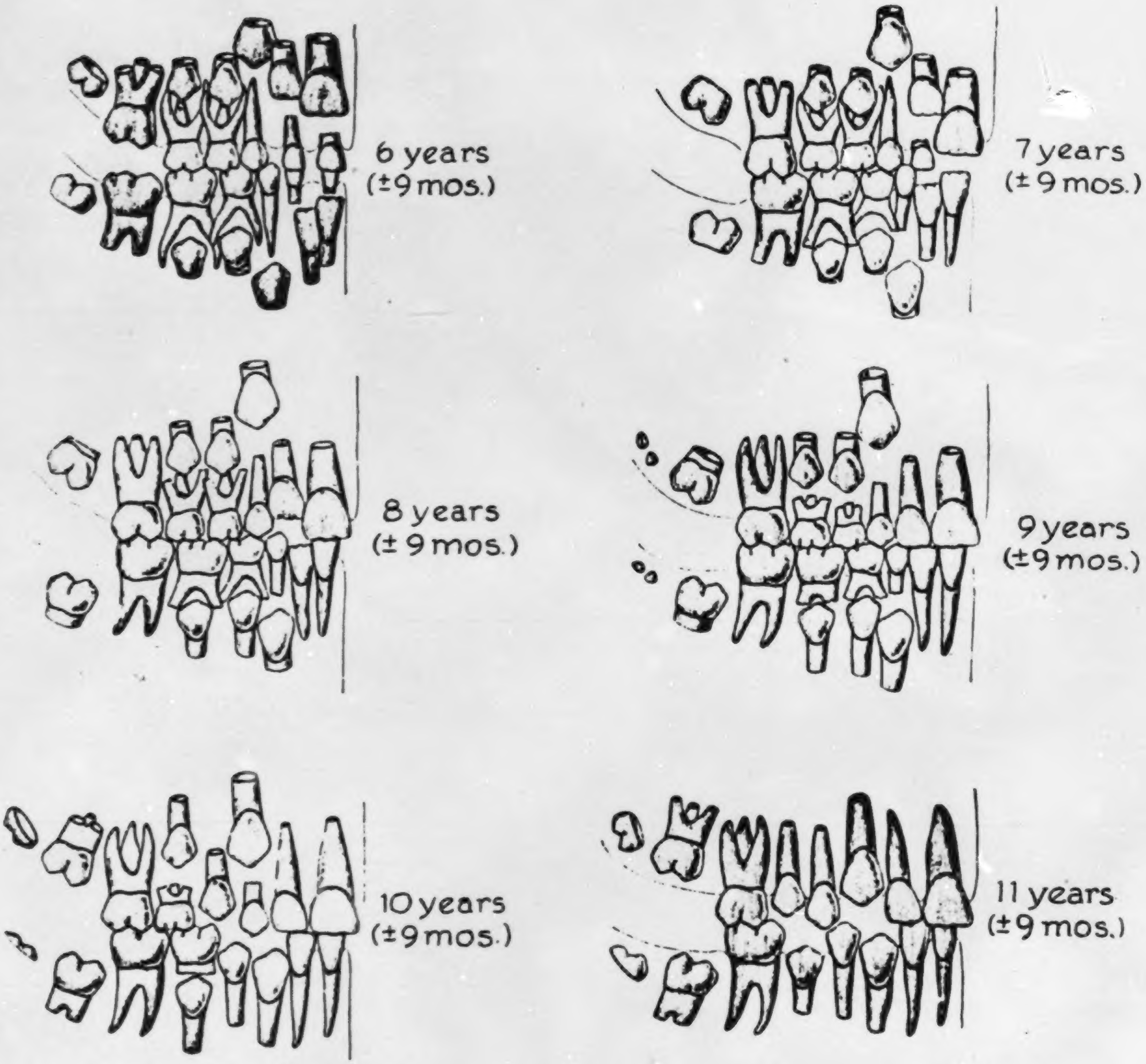


FIGURE 4: *Development of teeth from ages six through eleven.*

The second molars appear during the early teens, while the third molars erupt during the late teens or early twenties. The third molars are commonly known as "wisdom teeth" (Figure 5).

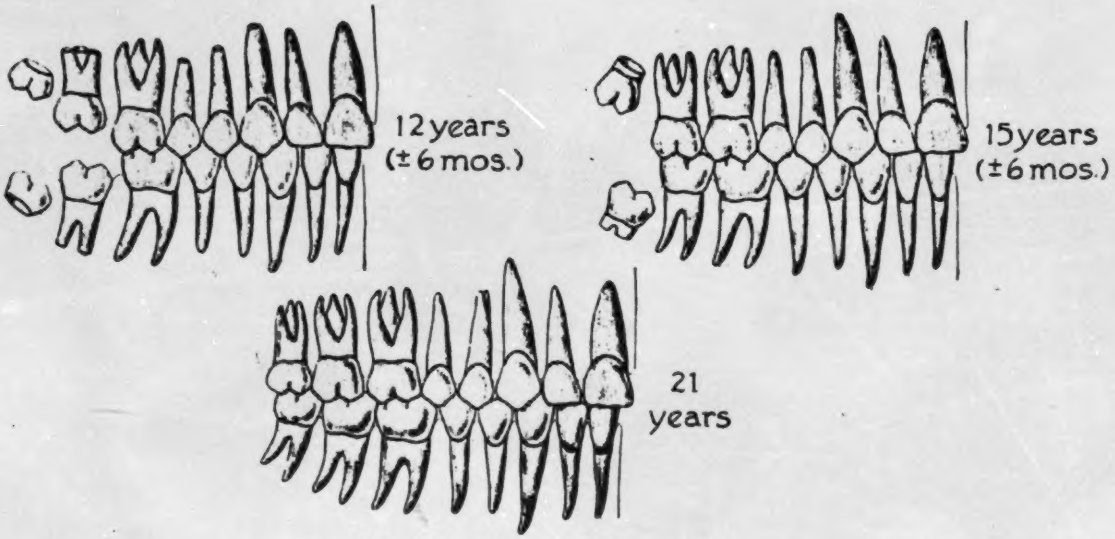


FIGURE 5: *Development of teeth from ages twelve to twenty-one.*

41-2 Occlusion and Malocclusion

What causes malocclusion? How can it be corrected?

The word "occlusion is derived from a Latin word meaning "to close." In dentistry it refers to the closing of the jaws so that the upper and lower teeth are in contact. Proper occlusion exists when each lower tooth meets correctly with its upper counterpart.

The word malocclusion refers to improper alignment of upper and lower teeth. Several factors may cause teeth to be positioned improperly. Some of these factors are hereditary, while most are environmental. Malocclusion is most likely to develop between the ages of six and ten, when the first molars erupt and permanent teeth replace deciduous teeth.

Some problems of malocclusion are related to improper development of the jaw. One type of malocclusion is overbite, sometimes referred to as "buck teeth." Overbite is the condition in which the upper jaw extends in front of the lower jaw. A slight overbite is normal and desirable, but a large overbite causes the teeth to meet incorrectly. Overbite is usually inherited, but a habit like thumbsucking is often the cause of this condition.

Underbite is the opposite of overbite. It is the condition in which the lower jaw extends in front of the upper jaw. Underbite may be hereditary, but it may also be a sign of a disease characterized by increased secretion of growth hormone. This is called acromegaly. In adults it causes certain bones, the lower jaw being one, to grow larger. Often the first sign of acromegaly is a change in occlusion. Malocclusion can also be due to insufficient space for the developing teeth.

Among primitive peoples, whose teeth are used to chew tough foods, malformations of the jaw are rare. Our civilized diets of soft foods give the jaw little exercise, and the lack of exercise may cause the jaw to fail to develop completely.

The teeth may also fail to align themselves properly if an unnatural force is repeatedly exerted on the jaw. The unnatural force may come from sucking the thumb or resting the jaw in the hands over long periods of time. Jaw development may also be influenced by malnutrition.

We have discussed malocclusions caused by improper positioning or development of the jaw. Other types of malocclusion are caused not by the jaw but by the teeth themselves.

Deciduous teeth reserve a space for permanent teeth. If a deciduous tooth is lost prematurely, another deciduous tooth may move toward its space. The permanent tooth is then forced to erupt in a position where it should not be. Early loss of deciduous teeth may be hereditary, but it also may be caused by disease.

When a permanent tooth is lost, the teeth to either side move into the space, causing malocclusion. Upper and lower teeth help to keep their counterparts in position; if one is lost, the other can move more easily. If a lower tooth is lost, the tooth above it may move down. The loss of permanent teeth is rarely caused by hereditary factors; it is caused by dental disease or decay, or by accident.

Occasionally a person will have too many teeth, a condition known as supernumeracy. As a result, the teeth are crowded. An extra tooth on top may not be paired with a bottom tooth. The result is malocclusion. Supernumeracy is presumed to occur in the development of the embryo; however, it has not been shown to be inherited. Supernumerary teeth do not always erupt. They may remain embedded in the bone and must be detected with X-rays.

Severe malocclusion makes chewing difficult. If chewing is difficult, either soft food must be eaten or food must be swallowed in larger pieces. But large pieces of food cause digestive problems and soft foods do not give the teeth, gums and jaws the stimulation necessary for proper blood circulation.

Malocclusion also causes increased susceptibility to dental disease. If teeth are not aligned properly, food is more easily caught between them; and some surfaces may be impossible to reach with a toothbrush. Malocclusion can also be the cause of speech defects and of distortion of facial features. Finally, malocclusion can cause psychological upset in some individuals. The relation between malocclusion and a person's appearance is often a major consideration in deciding whether or not to have treatment.

Malocclusion from environmental causes may be prevented. Habits such as thumbsucking can be discouraged. The diet can be of a consistency to give the jaws and teeth sufficient exercise. And the diet can provide good nutrition during the period of development of the teeth.

Malocclusion is, in many cases, correctible. There is a special kind of dentist whom you may have met. The primary job of this specialist is to correct improper alignment of teeth. We are referring to an orthodontist. Methods to correct malocclusion include metal bands to force the teeth into the proper position and removal of teeth to make room for other teeth to move into proper alignment. Extreme underbite may be treated by surgery to shorten the lower jaw.

Children often have a space between the front two incisors. Why does this space usually close up later?

Why do the deciduous teeth become loose and fall out?

In what order do the permanent teeth erupt?

How many permanent teeth are there? How many of each type?

What is occlusion? Malocclusion?

How does dental disease contribute to malocclusion?

How does malocclusion contribute to dental disease?

Vocabulary:

deciduous teeth (dee-SID-you-us)--the first set of teeth, popularly called "baby teeth," that fall out and are replaced by the permanent ones.

malocclusion (MAL-oh-KLU-jhun)--improper relationship between the upper and the lower teeth when the jaws are closed.

occlusion--the closing of the jaws so that the upper teeth contact the lower ones.

orthodontist (OR-tho-DON-tist)--a dentist who treats malocclusion.

resorption (re-SORP-shun)--the disappearance of tissue by absorption or dissolving.

SECTION 42: DENTAL DISEASE

42-1 What Are the Most Common Forms of Dental Disease?

There are many types of dental disease, but two are far more common than the others. One is dental caries, or cavities. Dental caries is a disease of the teeth which affects approximately 99 per cent of the population, adolescents being particularly susceptible. The other is periodontal disease, which affects the gums and other supporting structures of the teeth. Periodontal disease is the major cause of tooth loss in people over 30 years old.

Bacteria in the mouth and sweet foods are commonly mentioned as causes of dental caries. However, bacteria and sweets are not themselves the immediate causes of caries. The teeth are coated with a translucent substance that is continually secreted by the mucous membranes of the mouth. It is a good medium for bacterial growth. From the standpoint of many kinds of bacteria, the human mouth is a sort of paradise--warm climate (approximately 37 °C), lots of oxygen and all the food they can eat. These bacteria produce waste products that combine with the translucent substance to form a substance called plaque. Plaque is that gooey, white coating that you may have noticed on your teeth, particularly near your gums. The bacteria in plaque live on sugar. They consume sugar and from it produce acid, which they excrete. And this acid causes caries.

Bacteria are also the cause of periodontal disease. The supporting structures of a tooth are the gums, jawbone and periodontal membrane, which attaches a tooth to the jawbone. These are the structures affected by periodontal disease.

We will mention two types of periodontal disease. These are gingivitis and periodontitis. You may recall that the suffix "itis" means "inflammation."

Gingivitis is an inflammation of the gums, in which the gums often bleed when stimulated. Gingivitis arises from a number of causes, the primary and most important being plaque. Secondary factors include not chewing with certain teeth for a long time, nutritional deficiency, poorly-fitting dentures and malocclusion. It can also be caused by food trapped between the teeth and gums and by material called calculus. Calculus is a hard crust composed mainly of calcium phosphate that deposits in the plaque around the teeth. These deposits can irritate the gums and cause inflammation.

Periodontitis is also called pyorrhea. It usually begins as gingivitis, but as inflammation spreads the gum draws away from the tooth. The pocket which is formed fills with bacteria and pus. This weakens the supporting structure of the tooth and, if destruction of tissue is extensive, may cause loss of the tooth. The causes of periodontitis are the same as the causes of gingivitis: plaque and its products, trapped food, calculus deposits and malocclusion. It can be prevented by proper hygiene in the mouth and regular visits for dental care.

Whether the bacteria or the acid they excrete are the immediate cause of periodontal disease is not known, but in either event the disease is a result of the accumulation of bacteria in the mouth. Some dentists and dental hygienists, however, believe that calculus deposits are as important a cause of these diseases as bacteria are.

Other conditions besides caries involve loss of tooth substance. Two of these are erosion and abrasion. Erosion is the washing away of enamel by chemicals such as acids. Abrasion is mechanical wear. It may come from faulty brushing, abrasives in toothpastes or from chewing on such objects as bobby pins and pens. Abrasion is also caused by grinding the teeth.

42-2 Prevention of Dental Disease

How may dental disease be prevented?

The most direct and immediate way to prevent dental disease is to keep one's mouth clean. The object of cleaning is to remove two items: food particles and plaque. Bacteria are always in the mouth and continually multiplying, but regular removal of plaque keeps the bacteria population low. Removing food particles prevents bacteria from converting food to acid.

The teeth are cleaned by brushing the surfaces and flossing between the teeth with dental floss. Flossing is important because it reaches some areas not accessible to a toothbrush.

The formation of plaque and the growth of a population of bacteria takes about 24 hours. If you could brush your teeth at the same time each day and cover the entire surface every time you brushed, it would be sufficient to brush your teeth once a day. However, since it is likely that you miss areas of the teeth each time you brush, you should brush at least twice a day. The most effective time to brush is after meals, because not only are bacteria and plaque removed, but food particles as well, before they are used by bacteria. Brushing prevents calculus deposits from forming as well as removing food, bacteria and plaque. It also helps maintain healthy gums by massaging the gums.

It is especially important to include the use of dental floss in the care of the teeth. If the teeth are flossed correctly, once a day is sufficient. Flossing correctly does not mean simply putting the floss between each pair of teeth, but wrapping the floss around the edge of the tooth as well. The object is not only to remove food from between the teeth, but to scrape off plaque and bacteria also.

Most dentists recommend a toothbrush with soft bristles. Soft bristles are more effective in removing particles from between teeth and gums and are less likely to irritate gums, or abrade the tooth enamel, than hard bristles.

Both the inner and outer surfaces of the upper teeth should be brushed with a downward motion, from the gums toward the bottoms of the teeth. The inner and outer surfaces of the lower teeth should be brushed upward, also in the direction away from the gums. The chewing surfaces should be brushed back and forth with a scrubbing motion (Figure 1). This is one of several acceptable methods for brushing the teeth.

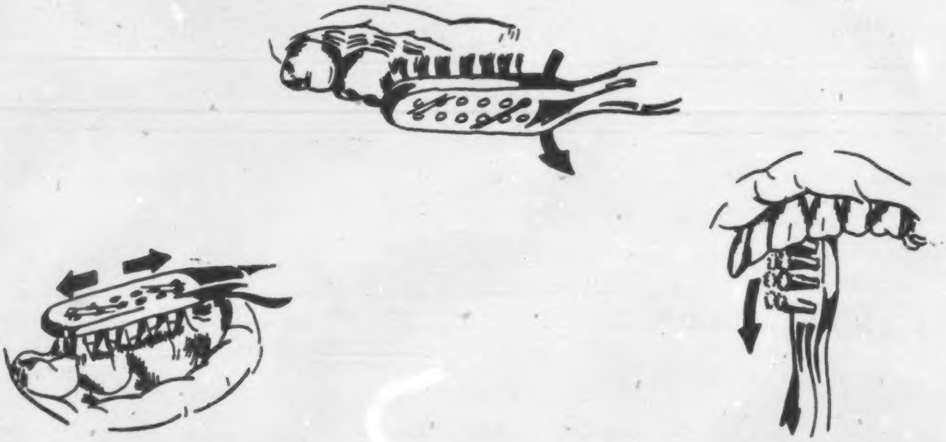


FIGURE 1: *One of several techniques for brushing teeth.*

In people over 30 the most common cause of tooth loss is not caries but gum and bone disease. The use of dental floss has therefore taken on as much, if not more importance than brushing in that age group. Flossing prevents calculus formation between the teeth, a common cause of gum infection.

Toothpaste or tooth powder should be used. Some people make a paste by mixing two parts of baking soda with one part of table salt. This mixture should be used only occasionally because it is abrasive and may cause damage to the enamel. The purpose of toothpaste is to clean the teeth and prevent the formation of caries. Many of the extravagant claims made for toothpastes based on the fact that they contain special chemicals are not warranted. A good toothpaste cleans the teeth and is not harmful to the teeth. In particular, a toothpaste should not be acidic because acid erodes enamel.

Some persons use electric toothbrushes. This type of brushing is not as efficient as manual brushing when the latter is performed correctly. However, an electric toothbrush may be prescribed for people with gum diseases because of its effective stimulation of the gum tissues.

Some people are now using water picks. These consist of a plastic tube through which water is forced by an electric motor.

Many dentists agree that they can be of help in cleaning between the teeth. However, if a person decides to use one, he should consult his dentist for directions to avoid possible damage to the gums. For example, if one uses the water pick continuously on a high-power setting or points it directly between the teeth, he may cause irritation and recession of the gums.

We have thus far restricted our discussion of prevention of tooth disease to cleaning the mouth. Dental health may also be approached by increasing the resistance of teeth to decay. Intake of the proper vitamins and minerals while teeth are developing results in more resistant teeth. The use of fluorides creates stronger teeth, but we will defer discussion of this controversial topic to Section 43.

A new procedure that has been developed to increase the teeth's resistance to decay involves coating the teeth with a polymer. The teeth are cleaned and dried, and a solution of the polymer is applied. It is exposed briefly to ultraviolet light, and the surfaces of the teeth are sealed, protecting them against caries. This adhesive polymer should be applied soon after a tooth erupts.

Our own saliva may also help protect our teeth from decay, by acting as a buffer. A buffer solution is defined as a solution that will maintain a nearly constant pH (concentration of H^+ ions) even when small amounts of H^+ ions or OH^- ions are added to it. If our saliva is indeed capable of acting as a buffer, then it may be able to prevent some of the acid produced by bacteria from eroding the enamel of the teeth by neutralizing the H^+ ions.

Diet is also important in dental health. Decreasing the amount of sugar in the diet decreases the amount of food available for bacteria to convert to acid. Sticky candies are especially bad, since they remain stuck to the teeth and are available to the bacteria for a longer period of time.

Antibiotics may eliminate bacteria from the mouth. Individuals using penicillin for other medical purposes have been found to develop fewer caries. However, the intake of antibiotics can cause other problems and this is not a recommended method of preventing dental disease.

42-3 Treatment of Dental Disease

How do dentists treat dental disease?

Despite the various means used to prevent dental disease, almost all of us develop caries in our teeth. A toothbrush or floss cannot fit into a cavity to remove food or bacteria, and the bacteria remain to cause further decay. If decay is not too extensive, a tooth is filled.

You probably know about the filling of teeth from personal experience. A dentist drills the tooth to remove bacteria and diseased tissue. The drilling also forms a pocket which holds the filling material. After drilling the tooth the dentist cleans the hole and usually coats it to insulate the nerve against changes in temperature. He then seals the cavity with filling material to prevent bacteria from re-entering (Figure 2).

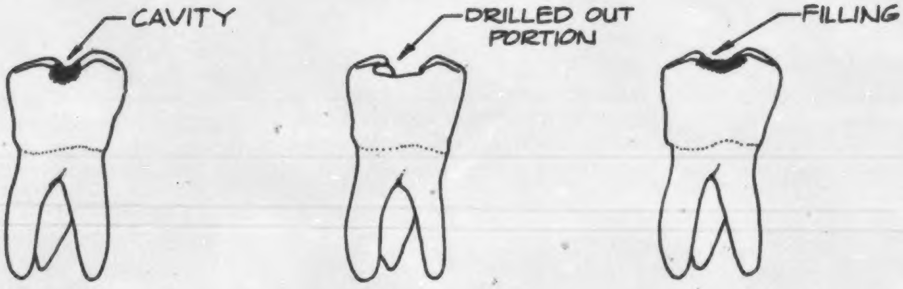


FIGURE 2: *How a tooth is filled.*

Many different materials are used for filling teeth. Among the materials are gold or a mixture of silver, tin, copper, zinc and mercury, known as amalgam. Material with a plastic base is often used in the front of incisors, because the material looks like tooth enamel. Plastic material was not used until recently in biting surfaces, because it was not strong enough. However, a plastic with quartz fibers was recently developed which can be used on all surfaces.

If the crown is badly decayed but the pulp is intact, the dentist may replace the crown with an artificial one. To do this he first grinds the tooth down to a peg. The artificial crown is cemented over the peg and extends slightly under the gum. Crowns are made of either gold or porcelain.

If decay progresses through the enamel and dentin to the pulp, the pulp becomes inflamed. When decay has progressed to this point, it is sometimes necessary to remove the tooth. However, modern root canal techniques can frequently save these teeth.

If it becomes necessary to remove a tooth, it should be replaced with a bridge. A bridge is a false tooth set in a frame which is connected to the teeth on either side. Bridges may be removable or permanent. A bridge is required to prevent malocclusion, because without a bridge the teeth on either side will move into the gap left by the missing tooth.

Periodontal disease is treated by first removing the source of irritation. Cleaning removes bacteria and food. Scraping the teeth, a process called scaling, removes calculus and stimulates the gums. This increases circulation. If malocclusion is present it is corrected, and improperly fitting dentures are replaced. In addition, the diet is often changed to improve the condition of the gums.

Our discussion of dental hygiene cannot be complete without a few comments on one of television's favorite subjects, "bad breath." Most mouth odors can be traced to unsanitary conditions in the mouth--food trapped between the teeth, decaying teeth, periodontitis. Thus bad breath may be the outcome of poor techniques of flossing and/or brushing, or it may be a symptom of a dental disease. Sometimes mouth odors may be due to other diseases such as uncontrolled diabetes or chronic nasal or sinus infections. Certain foods may impart a "bad" odor to the breath.

Evidently people have been concerned about their breath for a long time. In fifth-century Europe, a mouthwash was concocted by suspending the following in water: ashes from the head of a rabbit mixed with dried powdered mice plus an equal portion of pulverized marble. While modern mouthwashes are less obnoxious in contents and come nicely packaged, they have little or no value in dental hygiene. They temporarily camouflage the "effect," but do not relate to the "cause" of the problem.

42-4 Carbohydrates and Dental Health

How may carbohydrates affect the health of teeth?

During World Wars I and II, refined sugars and other highly refined carbohydrates were not as available as they have been at other times. One result was a decrease in the occurrence of dental caries. To understand the relation of sugar to caries, recall the role of bacteria in the mouth. Bacteria consume sugar and convert it to acid. Acid erodes the enamel of the teeth.

Sugar is available to bacteria for immediate consumption, but starch must first be broken down to sugar. Starch is broken down by the enzyme amylase, which is in saliva, but the process takes time. Only a fraction of the starch in the mouth is converted to sugar, the rest passing to the stomach unchanged. Consequently only a fraction of the starch eaten is available to bacteria in the mouth.

Certain sweet-tasting alcohols called sugar alcohols are also digested slowly and are therefore not readily available to bacteria. This fact is taken advantage of by using these alcohols in sugarless gum.

The worst sugars for your teeth are those that remain in your mouth longest. Candy that sticks to the teeth is particularly bad. Sweets in solution are better, because they pass through the mouth most readily.

Would you expect Eskimos and Indians to have more or fewer caries than other people? An investigator named Price obtained the information given in the table on the following page.

Numbers and Percentages of Carious Teeth Found in Indians and Eskimos at Various Stages of Civilization

Condition	No. of persons	No. of teeth	Carious Teeth No.	Carious Teeth Per cent
		Eskimos		
Isolated	72	2,138	2	0.1
Near civilization	81	2,254	394	17.5
		Indians		
Very primitive	76	2,144	0	0.0
Rather primitive	11	320	4	1.3
Near civilization	70	1,878	405	21.6

The comparison is dramatic: 72 isolated Eskimos had a total of only two teeth with caries; among Eskimos living near civilization, 17 per cent of their teeth had caries.

Price divided Indians into three groups: very primitive, rather primitive and near civilization. Of the 76 "very primitive" Indians examined, not one had any caries! Eleven Indians considered to be "rather primitive" had four caries among them. However, over one-fifth of the teeth of Indians living near civilization were found to have caries.

The near-absence of caries among "primitive" people has been attributed to two factors. One is the absence of refined sugars in their diets. The other is that their food is tough and requires chewing. Chewing is good for dental health: it stimulates the muscles, improves circulation, and increases saliva secreation which helps clean food from the teeth. Exercising the teeth and jaws also contributes to the healthy development of these structures.

Domestic animals also pay a price for living in civilization. Domestic animals have a much greater incidence of caries and gum disease than wild animals. Again this is due not only to refined food but also to soft food. Canned dog food, for example, does not give a dog's mouth sufficient exercise. It is not surprising that periodontal disease is common among dogs. If you have a dog, give it bones regularly (but make certain they are not soft bones, like chicken). Most veterinarians recommend hard, dry dog food.

What causes dental caries? What is periodontal disease?

What are two things you can do to help prevent dental disease?

When are fillings used? Crowns? Bridges?

Why is it important to replace lost teeth?

What is the treatment for periodontal disease?

What causes "bad breath?"

In what sense is caries a "disease of civilization?"

Vocabulary:

calculus (KAL-kew-lus)--a hard crust that deposits in plaque on teeth. It can irritate the gums adjacent to the teeth and cause ginvivitis and periodontitis.

caries--cavities in teeth caused by bacterial acid production.

gingivitis (JIN-jih-VY-tus)--inflammation of the gums.

periodontal (PAIR-ee-oh-DON-tul)--pertaining to the gums and bone that surround a tooth.

periodontitis (PAIR-ee-oh-don-TY-tus)--inflammation of the gums and bone around a tooth, often with pus; pyorrhea.

plaque--a white film that deposits on teeth, especially near the gums. Decay-producing bacteria live in it. It also forms a base for calculus deposits.

SECTION 43: VITAMINS AND FLUORIDES IN DENTAL HEALTH

43-1 Vitamins and Dental Health

Which vitamins are particularly vital to dental health?

When we discussed the roles of vitamins in the body, we mentioned several functions related to dental health. Now that we have considered teeth and surrounding tissues, we will re-examine the functions these nutrients have in dental health.

The outer parts of teeth are composed largely of calcium and phosphate. Vitamin D is necessary for the absorption of phosphate into the body from the intestines. It is also needed for the conversion of organic phosphorus to inorganic phosphates, the form in which phosphorus is incorporated into the bones and teeth. For these reasons vitamin D, as well as calcium and phosphorus, is necessary to the development of strong teeth.

Teeth (and bones, as well) also contain cells composed of organic material. These cells help in controlling the growth and resorption of the teeth. Vitamin A is required for the release of certain enzymes that are involved in the resorption of old cells and also laying down of new enamel. If a diet is deficient in vitamin A, the growth of new cells is inhibited and the development of bones and teeth is impaired. The enamel is particularly affected. Therefore, vitamin A is especially important while teeth are developing.

Vitamin C affects the soft tissue (the pulp and the gums) not only during the period of development but also later. Vitamin C, or ascorbic acid, is necessary for the formation of a protein called collagen. Collagen holds cells together and thus gives structure to tissue. A lack of collagen causes tissue to disintegrate. This problem is very rare in the U.S. where most gum problems are plaque-related.

You may recall that the group of symptoms resulting from a vitamin C deficiency is given the name scurvy. One of the symptoms is a condition known as hemorrhagic gingivitis. As we have discussed, gingivitis is inflammation of the gums. Hemorrhagic refers to bleeding. Thus hemorrhagic gingivitis is bleeding gums. A lack of collagen also causes a weakening of the structures that support the teeth and deterioration of the periodontal membrane. In extreme cases of scurvy, teeth become loose and fall out. Other effects of vitamin C deficiency are improper formation of dentin and deterioration of pulp.

The tongue is often an indicator of deficiency of a B vitamin. The tongue shows symptoms of deficiencies of riboflavin and niacin as well as the other B vitamins pyridoxine, biotin, folic acid and B_{12}. Symptoms vary from a red and swollen tongue to partial or total loss of taste buds.

43-2 Fluorides

How may fluorides prevent tooth decay?

An element that we have not yet discussed in relation to nutrition is very important in dental health. This element is fluorine. Fluorine, occurring as the F^- ion, helps to prevent the formation of dental caries. The drinking water of many communities contains fluorides naturally, and the dental health records of these communities first demonstrated the value of fluorides.

What initially called attention to the relation between fluorides and dental health was not the lack of caries. In was mottled enamel. The teeth of people in certain communities, mostly in the Southwest, were found to have a tendency to become pigmented--to stain a dark brown. This occurred when the concentration of fluoride in their water exceeded two parts per million (ppm). The positive value of fluoride was discovered when it was found that these people with mottled enamel developed fewer caries than the rest of the population. This prompted a great deal of research on fluoride in relation to dental health.

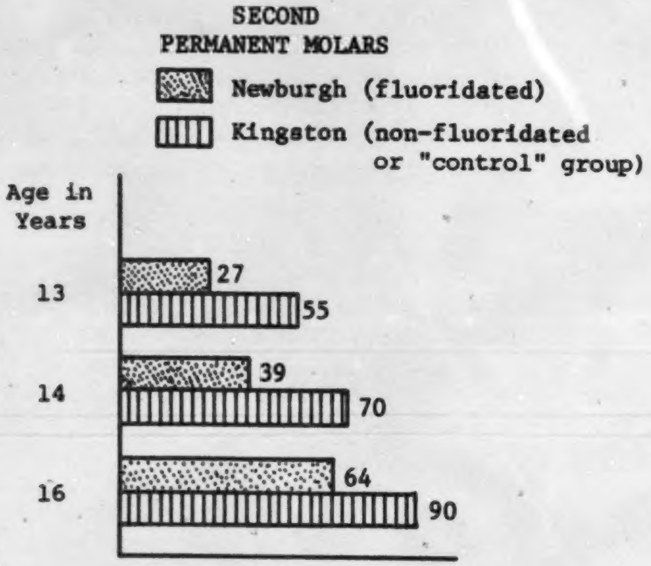
In the table on p. 245 are listed the concentrations of fluorides in the water of 13 communities. The data are listed from highest to lowest fluoride content of drinking water. Concentrations are given in parts per million. Also listed are the percentages of children with no tooth decay and the average number of diseased teeth per child.

	Fluoride content (ppm)	No. of children examined	Children with no tooth decay (per cent)	Average no. of diseased teeth per child
Colorado Springs, Colo.	2.6	404	28.5	2.5
Galesburg, Ill.	1.9	273	27.8	2.4
East Moline, Ill.	1.2	152	20.4	3.0
Kewanee, Ill.	0.9	123	17.9	3.4
Pueblo, Colo.	0.6	614	10.6	4.1
Marion, Ohio	0.4	263	5.7	5.6
Lima, Ohio	0.3	454	2.2	6.5
Middletown, Ohio	0.2	370	1.9	7.0
Zanesville, Ohio	0.2	450	2.6	7.3
Quincy, Ill.	0.1	330	2.4	7.1
Portsmouth, Ohio	0.1	469	1.3	7.7
Elkhart, Ind.	0.1	278	1.4	8.2
Michigan City, Ind.	0.1	236	0.0	10.4

The correlation between fluoride content of the water and dental health is very strong. In towns with 0.1 part per million fluoride in the water only about one to two per cent of the children had no tooth decay. In Colorado Springs, which has 2.6 parts per million fluoride, and Galesburg, Illinois, with 1.9 parts per million, over a fourth of the children had no decay. On the average, a child in Colorado Springs or in Galesburg had approximately 2.5 diseased teeth. Children in Michigan City, Indiana, had an average of 10.4 diseased teeth.

The statistics given above indicate that fluorides can help prevent tooth decay, but they also raise a series of questions. Is fluoride more effective with people of certain ages? Does fluoride reach teeth through the blood system or directly from saliva? How does fluoride act to make teeth more resistant to caries? What is the optimal concentration of fluorides in drinking water? The answers to some of these questions have not been completely determined, but we will state what is known.

A study of two similar neighboring cities on the Hudson River in New York, the cities of Newburgh and Kingston, provided valuable data on the effectiveness of fluoridation. Ten years before the study was made Newburgh artificially fluoridated its water to produce drinking water with a concentration of about one part per million of fluoride, a value that would not lead to mottling. During this period, Kingston had water that was not fluoridated. The chart on the following page gives the numbers of decayed, missing and filled second molars for teenagers. It represents a sample of the data obtained.



Number of decayed, missing and filled teeth per 100 erupted teeth.

What does this comparison indicate? It shows that for each of these age groups, the children receiving fluoridated water averaged fewer decayed, missing and filled second molar teeth than the control group. Similar findings on the first molars were also reported. In summary, the Newburgh children showed 60 per cent less tooth decay than their Kingston counterparts. A similar comparative study was done in Grand Rapids and Muskegon, Michigan. Grand Rapids children received added fluoride in their drinking water while those in Muskegon did not. The study was to be a ten-year survey as in the Kingston-Newburgh one but after five years, the results were so clearly in support of fluoridation that the Muskegon community demanded that their water be fluoridated. They no longer wanted to be a control group.

In addition to statistical studies of fluoridation, laboratory research has also been done. It has been found that fluoride is located mainly in the outer layers of enamel. This is true in both teeth that have erupted and those that have not erupted. Since unerupted teeth are not in contact with saliva most fluoride must reach these teeth from the blood system, not from saliva.

An important word encountered frequently in biomedicine is systemic. Systemic means "pertaining to the systems of the body." We say that fluoride reaches teeth systemically, because it reaches teeth from the blood system.

The enamel of the teeth is largely composed of calcium phosphate. The role of fluoride is not well understood chemically, but it appears that a small amount of fluoride ion makes calcium phosphate (and enamel) less susceptible to attack by acids.

What about fluoridated toothpaste? The fluoride in toothpaste reaches teeth not systemically but mainly through direct application.

When something is applied from outside the system of the body, we say that it is applied topically. Toothpaste is thus applied to teeth topically.

Because fluoridated toothpaste is applied topically, it is not as effective as fluoridated drinking water. Nevertheless, it helps prevent caries in the teeth of young people. The American Dental Association and almost all dentists recommend its use.

43-3 What Are the Dangers of Too Much Fluoride?

It should be remembered that too much fluoride, just as too much of other minerals, can cause serious medical problems in man. Where the drinking water contains excessively high fluoride concentrations (as in certain parts of India) people's teeth are commonly mottled. In the extreme case, at about 30 years of age, pain and stiffness of the spine and joints develop until eventually the entire spine becomes a continuous column of bone. These symptoms are very similar to the severe cases of skeletal fluorosis found in people who work in industries where excess fluorine tends to get into their bodies (aluminum factories, steel mills and enamel factories). For these reasons, many people oppose the addition of fluorine to their water. Fluoridation of water, like any other health care measure that affects a whole community, can become a political issue. You will be investigating the politics of health care in Unit III of Biomedical Social Science.

Proponents of fluoridation, including the American Dental Association and the U.S. Public Health Service, argue that there is no chance of fluoride poisoning from artificially fluoridated water. They point to the fact that the people in Bartlett, Texas, whose drinking water is naturally eight times the recommended concentration of fluoride, have no known increase in any disorder except for mottled teeth. Even this disorder does not result from the concentration of fluoride in artifically fluoridated water.

What roles do vitamins play in the development and maintenance of healthy teeth?

What vitamin is associated with hemorrhagic gingivitis?

What were the highlights of the Kingston-Newburgh fluoride study?

What is the difference between a "topical" and a "systemic" medicine or treatment?

Classify the following as systemic or topical: Aspirin, cough medicine, soap, handcream, vaseline.

What are the symptoms of too much fluorine in the body?

Vocabulary:

hemorrhagic (HEM-uh-RAH-jik)--characterized by bleeding.

systemic--present throughout the body.

topical--present only on the outside of the body.

fluorosis (fleur-OH-sis)--poisoning due to excessive fluoride.

UNIT REVIEW SET:

1. What areas of study are included within the field of nutritional science?

2. a. Name several factors which are thought to increase the risk of heart disease.

   b. On what type of evidence are these conclusions based?

3. a. What is accomplished during the digestive process?

   b. Name three classes of nutrients that can serve as sources of energy.

4. a. What are enzymes?

   b. What role do they play in digestion?

5. a. Where does digestion begin?

   b. What happens to food in the digestive organ immediately following the esophagus?

6. What is the relation of excess stomach acid to peptic ulcers?

7. a. What are the digestive functions of the liver, gall bladder and pancreas?

   b. Where does most food absorption occur?

8. Define hepatitis, gallstones, pancreatitis.

9. What are the major functions of the large intestine?

10. What role does water play in the life processes?

11. Define organic chemistry. Name three classes of organic substances that are also nutrients.

12. a. From what class of nutrients does the average American derive about half the daily energy requirement?

    b. In the form of which monosaccharide is digested starch absorbed?

13. a. Define hydrolysis.

b. What is the significance of this process in digestion?

14. a. What is the source of the glycogen that is stored in the liver?

b. What happens when the liver's capacity to store glycogen is reached?

c. Which important disease is thought to result from excess serum lipids?

15. a. Name the principal sweetening agent used in most American diets.

b. In which classes of nutrients are brown sugar, molasses, and unprocessed honey richer than the named sweetener?

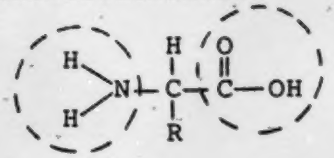
16. a. What is a triglyceride?

b. What substances form when a fat is completely hydrolyzed?

17. a. Contrast the chemical structures of saturated, monounsaturated and polyunsaturated fatty acids.

b. Discuss the relation of each of these three types of fatty acids to the risk of atherosclerosis.

18.



a. The above formula is a general formula for which class of nutrients?

b. Name the two circled functional groups.

c. Which nutrients are made from many such above "units?"

19. a. What do we mean by "essential" amino acids?

b. Which classes of foods are said to provide "complete" protein? What does this mean?

20. a. Name three minerals required by the body in at least milligram quantities.

b. Name two minerals that are required in trace quantities.

21. a. What is the cause of beriberi?

b. What is the relation between food processing and beriberi?

22. a. Why is the process of emulsification essential to human digestion?

b. What is the emulsifier secreted into the digestive tract?

c. Is this substance a hormone? Explain.

23. a. Distinguish between kinetic and potential energy.

b. In what form is the energy we derive from food?

24. a. What is meant by the statement that "energy is conserved"?

b. Discuss this principle in relation to cell respiration.

25. List the two general functions of metabolism.

26. Approximately how many calories does the body obtain from one gram of protein? One gram of carbohydrate? One gram of fat?

27. What is accomplished by cell respiration?

28. What is the role of adenosine triphosphate (ATP)?

29. Endothermic reactions tend to favor reactants over products. Describe two ways in which the body causes such reactions to produce mainly products.

30. How is maturity-onset diabetes mellitus usually controlled?

31. What is the basic principle of losing weight?

32. What are some of the procedures used to prevent bacteria from multiplying in food?

33. a. Which animals common to the diet may harbor Trichinella worms?

b. How can the chance of contracting trichinosis be lessened?

34. Name two classes of contaminants sometimes found in drinking water.

35. Which nutrients present in whole wheat flour are significantly reduced in unenriched white flour?

36. a. List two uses of food additives.

b. Name two potentially harmful food additives. In what ways may they be harmful?

37. What can be learned about packaged foods from their labels?

38. What are the functions of the four different types of human teeth?

39. What kind of dental problem is treated by an orthodontist?

40. How do gingivitis and periodontitis differ?

41. Describe the complete process by which caries are formed.

42. Why is fluoride added to water?